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Evaluation of Dredged Material Management Plans for Michigan City

Prepared for:

USACE DETROIT DISTRICT

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Evaluation of Dredged Material Management Plans for Michigan City

Abstract

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1.0 INTRODUCTION

Regional Sediment Management (RSM) is a planning concept used to develop management objectives and action plans for nearshore, riverine and estuarine sediment within natural systems, such as Lake Michigan. Effective management requires broad participation from stakeholders and a study boundary definition based on the natural limits of sediment movement, not defined by geo-political boundaries. The U.S. Army Corps of Engineers (USACE) is presently evaluating alternatives to the existing dredging and beach nourishment practices at Michigan City Harbor, Indiana, within the context of RSM. The ultimate goal is a Dredge Material Management Plan (DMMP) that utilizes environmentally sound dredging / placement practices and respects the ideology of RSM.

Baird & Associates has been retained to assist the USACE in the development of a DMMP for Michigan City. This report summarizes an investigation to quantify historical shoreline changes, evaluate current dredging practices, and evaluate alternatives to manage sediment in future. Section 1.0 of the report will summarize the scope of the investigation, objectives of the study, harbor history, previous reports and observations from the site visit. The data, shoreline change measurements, sediment modeling and evaluation of alternatives will be discussed is subsequent sections of the report.

1.1 Scope of Investigation

The study area for the Michigan City DMMP investigation includes the South-East shoreline of Lake Michigan, from the New Buffalo Harbor in the North to Burns Harbor in the South-West. Figure 1.1-1 presents the study area bounded by the two harbors.

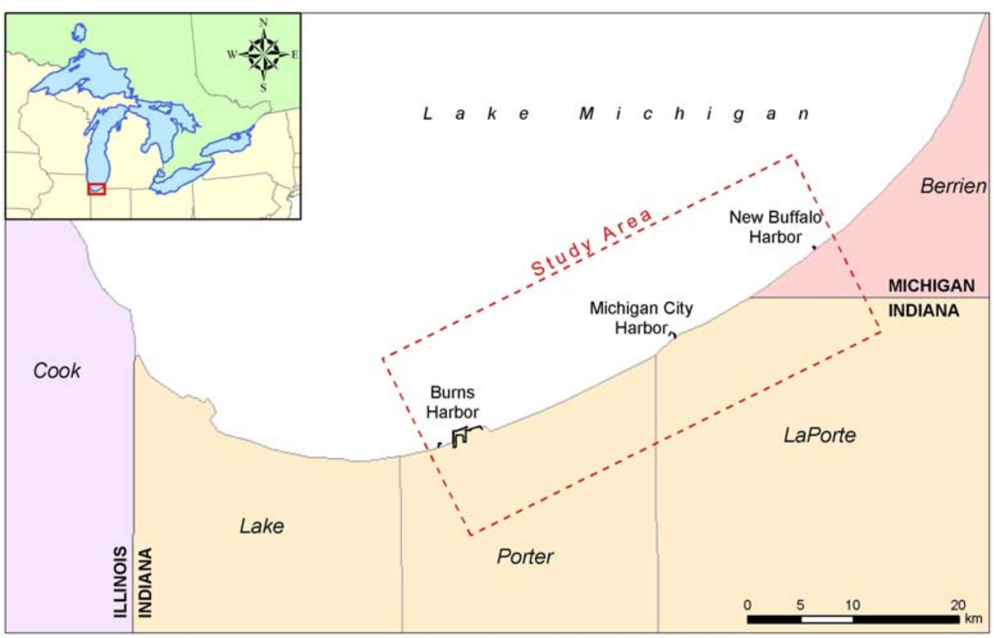


Figure 1.1-1 Regional Study Area

1.2 Objectives of Study

The objectives of the study are summarized in the bullet points below:

- Consider only environmentally sound dredging and disposal alternatives that incorporate sound engineering practice, meet all Federal standards and relocate an dredged material in the least costly manner,
- Assess beneficial uses for dredged material, such as improvements to fish and wildlife habitat and storm damage reduction,
- Develop a 20 year Dredge Material Management Plan for the Michigan City Harbor that addresses the following specific issues:
  - i. Shoaling problems at the mouth of the harbor,
  - ii. Nourishment requirements downdrift of the harbor,
  - iii. Protection of a critical dune area,
  - iv. Protection of critical wetlands,
  - v. Reduction of dredging at the Michigan City Marina, and
  - vi. Maintaining a safe swim area at the local state park.

1.3 Harbor History

The first piers at Michigan City were constructed in 1836 to stabilize the entrance to Trail Creek for navigation. A map depicting the old river entrance and piers is presented in Figure 1.3-1. In 1884 the 305 m East Breakwater was constructed (it was actually an offshore breakwater when constructed). A new East Pier was completed in 1902, followed by the Offshore Breakwater in 1903. The West Pier marked the completion of the principal harbor structures in 1909. The present harbor is presented in Figure 1.3-2 for reference.

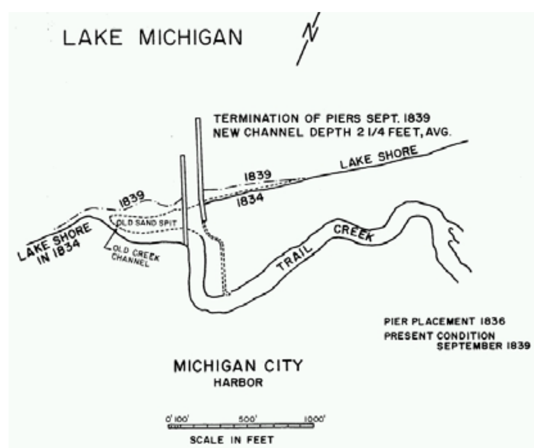


Figure 1.3-1 Original Harbor Structures

By 1913 significant accretion had occurred updrift of the structures and a tombolo formed between the shoreline and East Breakwater (Figure 1.3-2). The fillet beach has continued to grow above and below the water since the late 1800's, as seen by the shoreline position in the 2002 orthophotograph. Adjacent to the west pier, the NIPSCO lands were expanded between the 1930s and 1960s, then protected with a sheet pile wall and revetment. For additional information on historical shorelines, refer to the detailed discussion in Section 3.1.

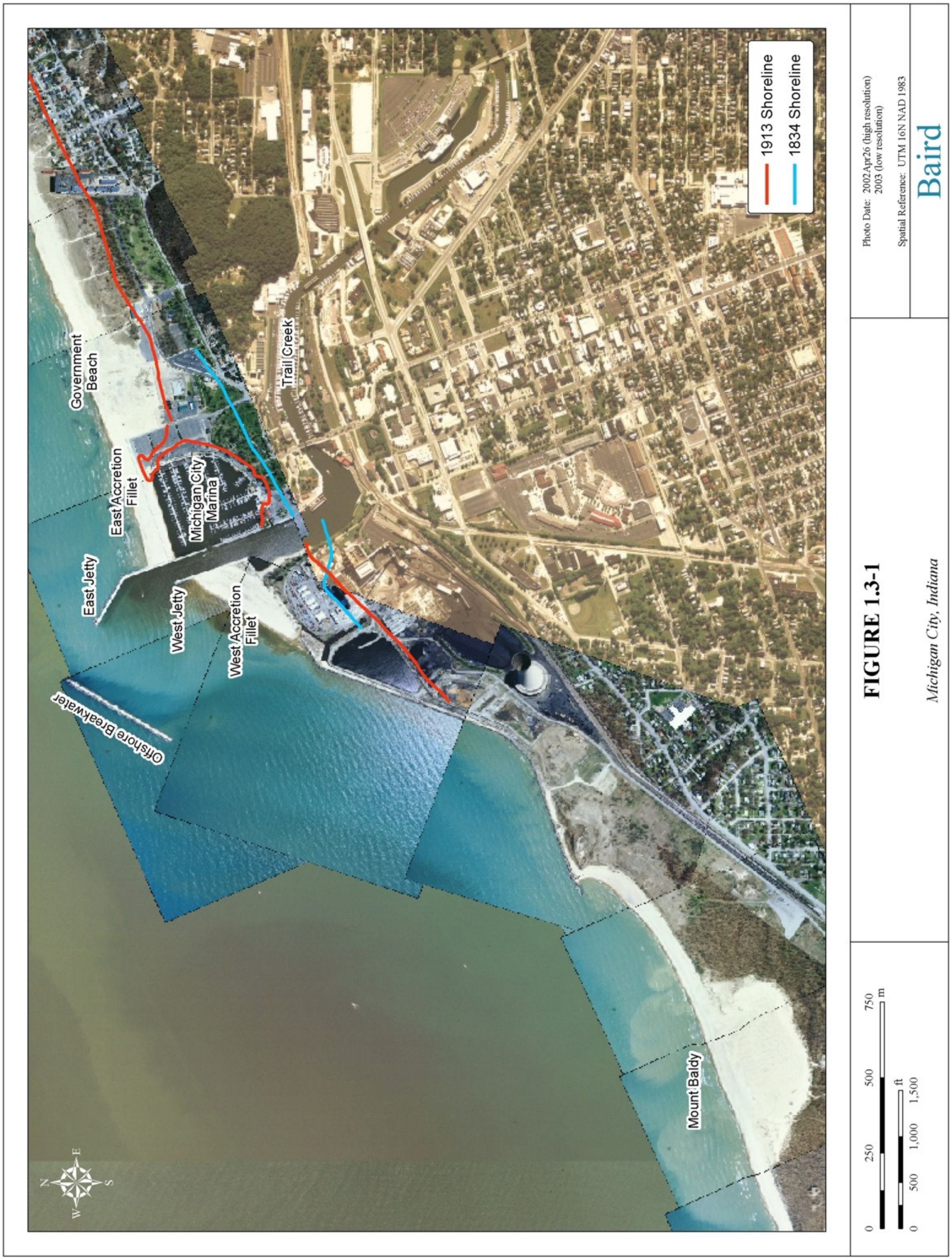


Figure 1.3-2 Michigan City Harbor and Surrounding Features

1.4 Previous Studies

A digital report entitled "Coastal Dynamics" is available from the Indiana Department of Natural Resources web site. Two chapters are of particular interest to this study, including "Conditions Along the Indiana Coastline" and "The Natural Coastline in Indiana". Key observations and data from the reports are summarized below:

- From the Michigan – Indiana state line to Gary, Indiana, the net direction of Longshore Sediment Transport (LST) is from east to west,

- Water levels and storms influence beach and dune conditions. For example, following high lake levels and severe storms, beaches will be sand starved and narrow. Conversely, following years of low lake levels and mild storms, the profile will recover and wide beaches will be abundant. This was also one of the major conclusions of the LMPDS (Baird, 2003),

- Man-made structures, such as shore parallel revetments and shore perpendicular jetties, influence volume of sediment available in the nearshore and on the beach,

- The High Erosion Hazard Area (HEHA) is defined as a portion of the shoreline with a long term erosion rate greater than one foot per year. In LaPorte County, a significant portion of the study area defined in Figure 1.1-1 is designated as a HEHA. For example, 95.7% of the 4,600 m of shoreline associated with Michiana Shores, Duneland Beach, and Long Beach is classified as a HEHA. The fillet beach is defined by a long stable stretch of shore known as Washington Park. This 3,400 m of shore is not defined as a HEHA.

- Between the NIPSCO shore protection west of the harbor and the revetment at Beverly Shores, the entire 6,100 m of shoreline is classified as a HEHA. This reach of shore includes portions of both LaPorte and Porter County.

- From the Michigan – Indiana state line to the east fillet beach at Michigan City, the entire 15,100 ft of shoreline has been armored with a rock revetment at the base of the eroding dune/bluff. Construction began in 1988 following the high lake levels of 1986. Interestingly, none of this revetment was visible during the August 2004 field trip (discussed further in Section 1.5).

- West of Mount Baldy, 13,000 feet of revetment was installed in 1974 along Lake Front Drive to protect the Town of Beverly Shores.

Of particular interest to the current study is the general classification of the shoreline within the study area (with the exceptions of the fillet beaches) as erosional. The field observations from August 2004 following several years of low lake levels provide a very different picture of the beach and dune conditions, particularly east (updrift) of the harbor. These observations are discussed below in Section 1.5.

1.5 Regional Site Conditions

A site visit was completed on August 10, 2004 by staff from Baird and the USACE. Based on the site visit observations and desktop studies, the shoreline from New Buffalo to Beverly Shores has been sub-divided into five reaches, which are described below.

The Lake Michigan water level on the day of the survey was 176.35 m IGLD'85, which is below the long term average for the month (176.6 m). It is also important to note that Lake Michigan has been in a prolonged period of low lake levels since 1999. Refer to the monthly mean water level plotted in Figure 1.5-1. This current trend of low lake levels is very similar to the lows experienced in the 1930s and 1960s and has exerted a significant influence on the beaches and dunes within the study area.

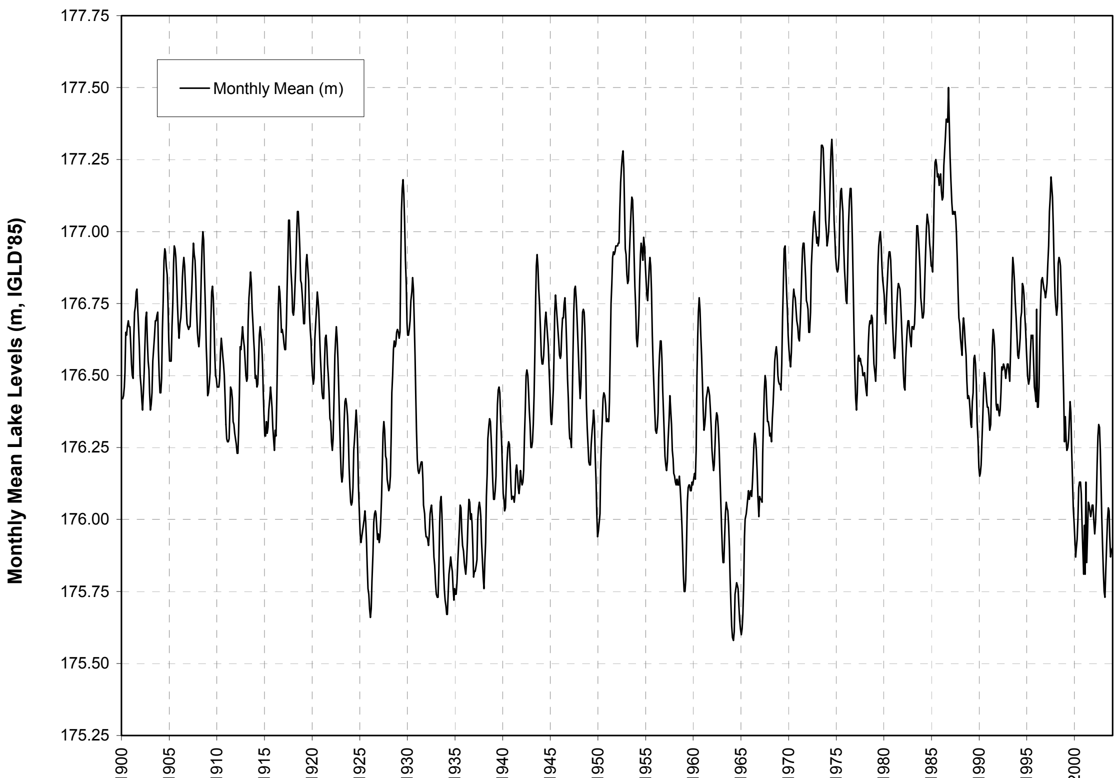


Figure 1.5-1 Historical water levels from 1900 to present, Lake Michigan

1.5.1 Reach 1 – New Buffalo to Grand Beach

Reach 1 is 5.4 km in length and extents from the west side of the New Buffalo Harbor to Grand Beach. A series of site photographs are presented in Figure 1.5.1-1 and described briefly. The Dunewood Private Development is located immediately downdrift the harbor. Photograph 1 is looking NE towards the harbor, while Photo 2 is looking SW. With the current water level regime on Lake Michigan, the dunes are fairly stable although the beaches fronting the dunes are very narrow. Controlled access to the beach helps to funnel traffic and preserves a healthy dune grass community.

A water intake facility was visited further to the SW and the beach conditions to the NE and SW are recorded in Photographs 3 and 4 respectively. A large revetment was constructed to protect the intake facility and it protrudes into the lake. With the exception of a small fillet beach on the NE side, the beaches were narrow and often featured shoreline protection structures at the base of the dune/bluff. Many of these structures were partially buried in August, 2004.

The Grand Beach community features a mixture of older and recent estate homes constructed along the shores of Lake Michigan. Photographs 5a and 5b present a typical home under construction in Grand Beach. Again, the beaches were very narrow and the backbeach was generally protected with some form of an armor stone revetment, as seen in Photographs 6 and 7 of Figure 1.5.1-1. The location of the steel seasonal stairs in Photo 7 provides some interesting data on the evolution of the beach. The adjustable base of the stairs was set to a beach elevation approximately 0.5 m higher than the observed conditions, suggesting the beach has eroded since the probably spring installation. Also, the remnants of the beach at a higher elevation is also seen in bands of laminated sand in the lower right hand cover of Photograph 7. Collectively, these observations suggest the beach has eroded significantly during the summer, likely in response to the rising lake levels.

The older portion of the Grand Beach community is protected with a substantial armor stone revetment constructed at the base of the dune. Refer to Photograph 8. With the current low lake levels, a beach is present in front of the revetment. During high lake levels, the beach would be submerged.

In summary, beaches were very narrow in Reach 1, especially given the last six years of low lake levels. Although there were no obvious signs of active shoreline erosion, the presence of extensive shoreline protection structures indicates this area has eroded in the past, such as the high lake levels of the mid 1970s, 1980s and 1990s. Residential development dominates the land use and it generally occurs on top of the foredune. This level of disruption to the natural system makes it difficult for the beach-dune system to recover and grow during periods of low lake levels, such as the last six years.

1.5.2 Reach 2 – Michiana Shores to Duneland Beach

Reach 2 covers approximately 3.8 km and includes the communities of Michiana Shores and Duneland Beach as seen in Figure 1.5.2-1. Controlled access to the beach is provided throughout Reach 2 (Photo 9) and the homes are separated from the dune by Lake Shore Drive (Photo 10). The foredune and primary dune are well vegetated and showed no signs of erosion (photographs 12-13). However, the State of Indiana reports indicate much of Reach 2 is located in the High Erosion Hazard Area and the entire shoreline was armored following the record high lake levels of 1986 to protect the road. After six years of low lake levels it appears the rock revetments, which were constructed at the base of the dune, have been completely buried by wind blown sand. These observations highlight the significant influence of lake level fluctuations on the dynamic beach – dune system of Lake Michigan.

Throughout the reach the beaches are very wide and provide natural erosion protection from storms during the current trend of low lake levels. These beaches have clearly responded more favorably to the low lake levels than Reach 1. Two possible explanations include: 1) less disruption to the dune system with controlled access points and residential development setback further from the shore, and 2) increased supply of sediment to the beach, both alongshore and cross-shore.

1.5.3 Reach 3 – Long Beach to Washington Park

The Long Beach community and Washington Park collectively represent the spatial extents of the updrift fillet beach at Michigan City and define Reach 3. The reach 5.4 km in length and features different development patterns than Reach 2. For Long Beach, a row of residential homes is located on the lake side of Lake Shore Drive, as seen in Photographs 14 and 15 of Figure 1.5.2-1. Although the homes and seawalls/revetments can have a negative impact on the beach and dune systems (as in Reach 1), the accumulation of sediment in the fillet beach is a more dominant process. Consequently the beaches in the Long Beach community are very wide under the present lake level regime and the dunes show no signs of erosion. Aeolian processes are very active and local residents have turned to mechanical solutions to manage the sediment at the back of the beach. For example, a tractor is used to excavate a set of access stairs in Photo 16. If the homes were replaced by a natural foredune, aeolian processes wouldn't be a problem.

Further to the SW, Photographs 17 and 18 record very wide beach conditions and an extensive dune system located between the first row of homes and the beach. This large volume of sand is sufficient to provide storm protection during low and high lake levels, and thus no shore protection is required.

1.5.4 Reach 4 – Michigan City Harbor and NIPSCO Plant

Reach 4 includes the Michigan City Harbor, Trail Creek, and the NIPSCO Power Plant. The entire shoreline is protected with hard structures, such as concrete and steel sheet pile walls and revetments. There is no natural shoreline and consequently no long term recession rate.

Photo 19 in Figure 1.5.4-1 records the widest expanse of the updrift fillet beach at Michigan City. A portion of the dune adjacent to the parking lot for Washington Park was mechanically removed to provide easy access to the waterline. Consequently, aeolian processes are very active across the wide beach in this area and sand deposition is common in the parking lot. The fillet beach currently extends in front of the east breakwater for the Michigan City Marina, as seen in Photo 20 (taken from the east pier). Consequently, aeolian processes also deposit sediment in the marina basin, as recorded in Photographs 21 and 22 (the seawall is under construction in Photo 22). Two of the three boat launches are inoperable due to this deposition.

The location of the offshore breakwater is noted on Figure 1.5.4-1 and presented in Photo 23. The structure features a low crest elevation and wave overtopping is common during storms. The west fillet beach is seen in Photo 24 looking in a SW direction across the west pier. Sediment didn't start accumulating in this fillet beach until after 1938 when the NIPSCO lands were expanded and protected with a sheet pile wall and revetment.

1.5.5 Reach 5 - Indiana Dunes National Lakeshore

Reach 5 is located within the Indiana Dunes National Lakeshore and represents approximately 3.3 km of shoreline. The reach is dominated by a massive parabolic dune known as Mount Baldy. A composite image of the dune taken from the waterline is seen in Photograph 25 on Figure 1.5.4-1. The interior of the parabola is unvegetated and actively eroding, while the side slopes feature a mature woodlot. Onshore winds blow sand up the gentle windward slope and deposit the sand on the steep outer slip face contributing to the landward migration of the dune. Based on the work of Hansen et al (2003) for similar parabolic dunes further to the north near Holland, Michigan, formation of Mount Baldy likely began 4,000 to 5,000 years before present (YBP), following the Nipissing high phase of Lake Michigan (Baedke and Thompson, 2000). Paleosols exposed in the eroding interior of the dune could be used to reconstruct the history of the dune using carbon dating techniques and optical luminescence.

The backslope or slip face of the parabola is actively migrating landward into the forest, as seen in Photograph 26. To some degree, this migration is accelerated by park visitors who use a nearby parking lot and access the lake by hiking up, over and down the dune. Although it is difficult to separate the retreat due to natural processes from the anthropogenic disturbance, the foot traffic is clearly contributing to the migration. Further to the SW, the relic dunes in the park are not actively migrating but do show signs of erosion, likely during high lake levels (Photographs 27 and 28). Presently, the beaches are moderate in width but very low crested. Small embryo dunes have formed at the base of the relic foredune due to aeolian transport of sand. Even a moderate increases in lake levels, such as 0.5 m, will substantially reduce the protective beach in front of these relic dunes and likely erode the embryo dunes.

The entire shoreline of Reach 5 is classified as a HEHA by the State of Indiana and Mount Baldy features the highest long term erosion rate for the State, at approximately 3 m/yr.

Reach 5 terminates at the Beverly Shores revetment, which was constructed in 1974. The revetment is almost 4 km in length and protects Lake Front Drive. The North-East terminus of the revetment can be seen in Photographs 29 and 30 of Figure 1.5.4-1.

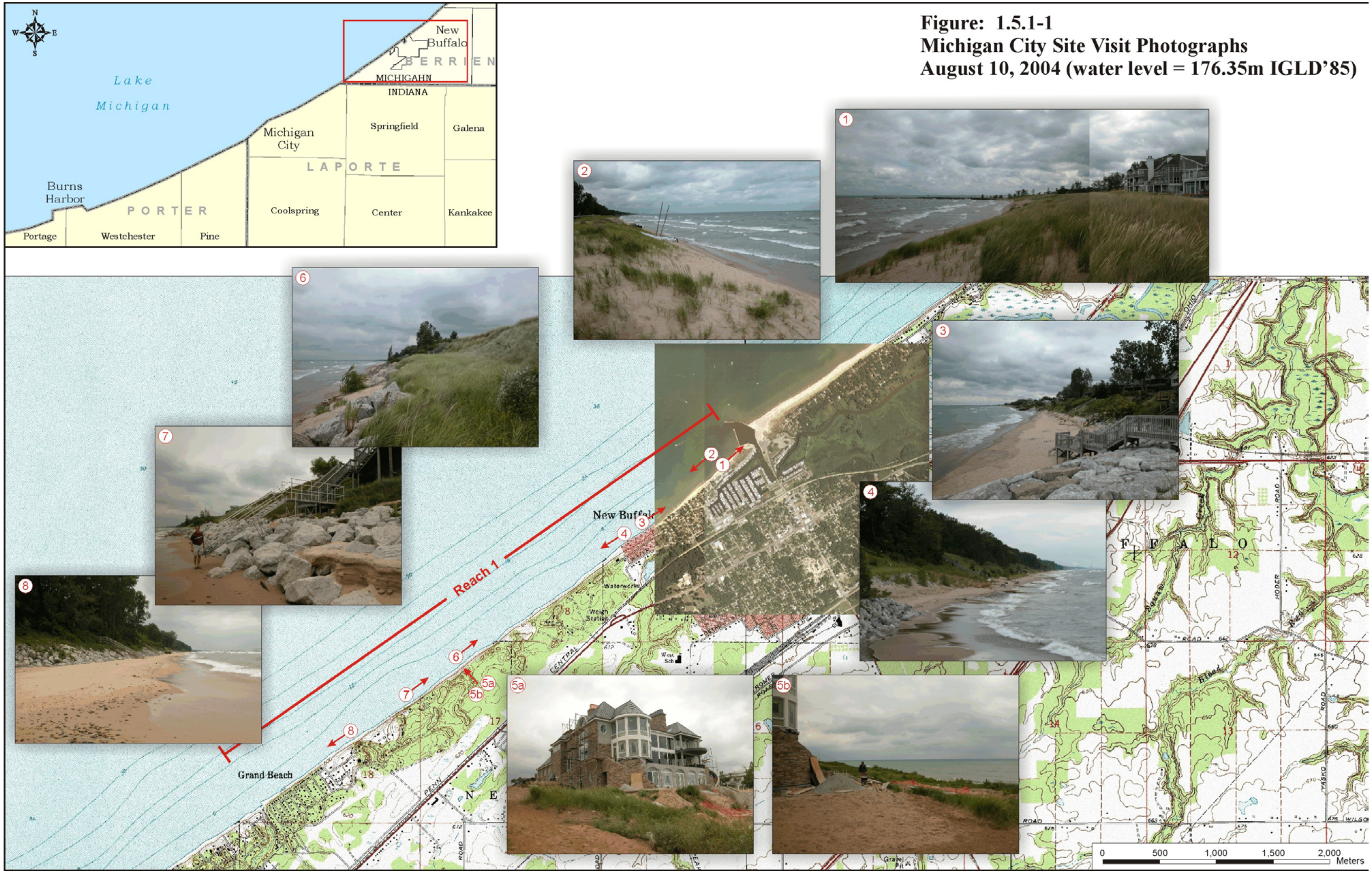


Figure: 1.5.1-1
Michigan City Site Visit Photographs
August 10, 2004 (water level = 176.35m IGLD'85)

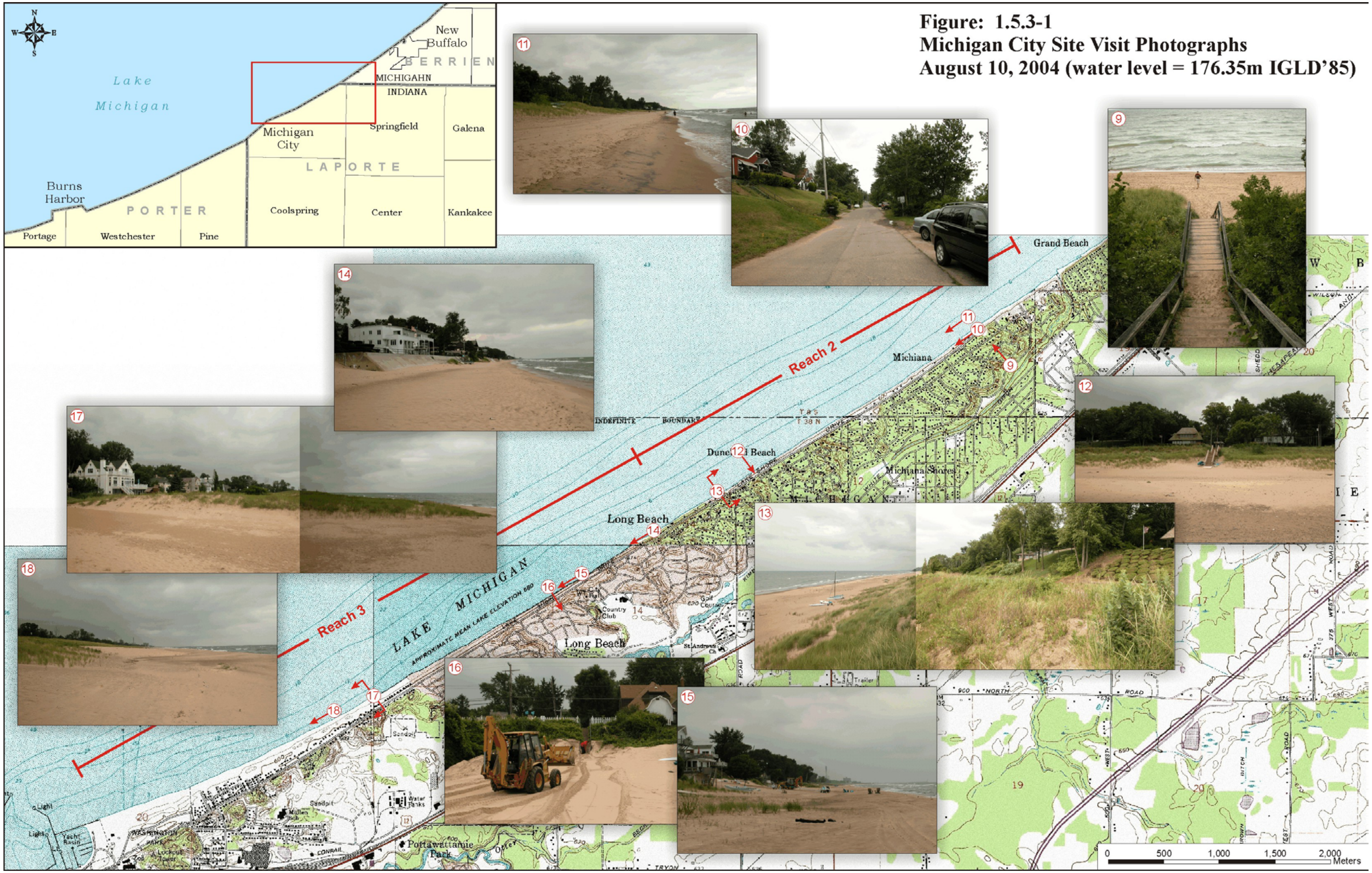
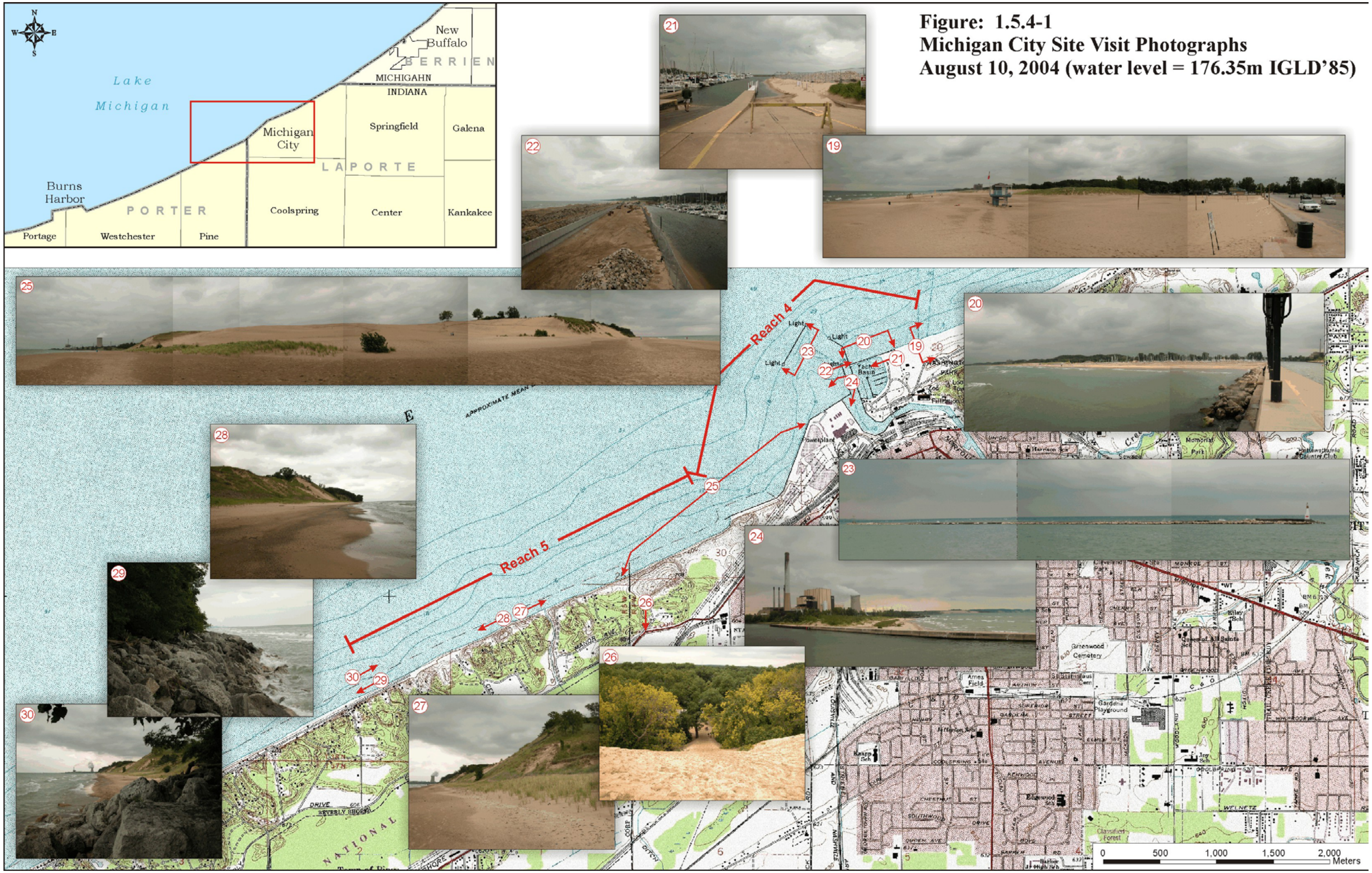


Figure: 1.5.3-1
Michigan City Site Visit Photographs
August 10, 2004 (water level = 176.35m IGLD'85)

Figure: 1.5.4-1
Michigan City Site Visit Photographs
August 10, 2004 (water level = 176.35m IGLD'85)



2.0 DATA COLLECTION AND GENERATION

Section 2.0 of the report describes the collection of spatial and temporal datasets, along with the creation of new data specifically for the investigation.

2.1 Spatial Datasets

The spatial datasets are described below, including bathymetry, topography, aerial photographs, and sub-surface data.

2.1.1 Bathymetry Data

The collection of bathymetric data from multiple temporal periods, particularly the historical periods, was a critical component of the investigation. The historical charts and recent bathymetric data sources are summarized below.

2.1.1.1 Historical Charts

Numerous historic charts were obtained from the national archives in Washington and the internal archives of the USACE. The charts are received in either paper or digital format. Scanned versions of the maps were registered with ArcGIS. Figure 2.1.1.1-1 provides a sample of the 1938 chart, which includes bathymetry data in the form of historical shorelines.

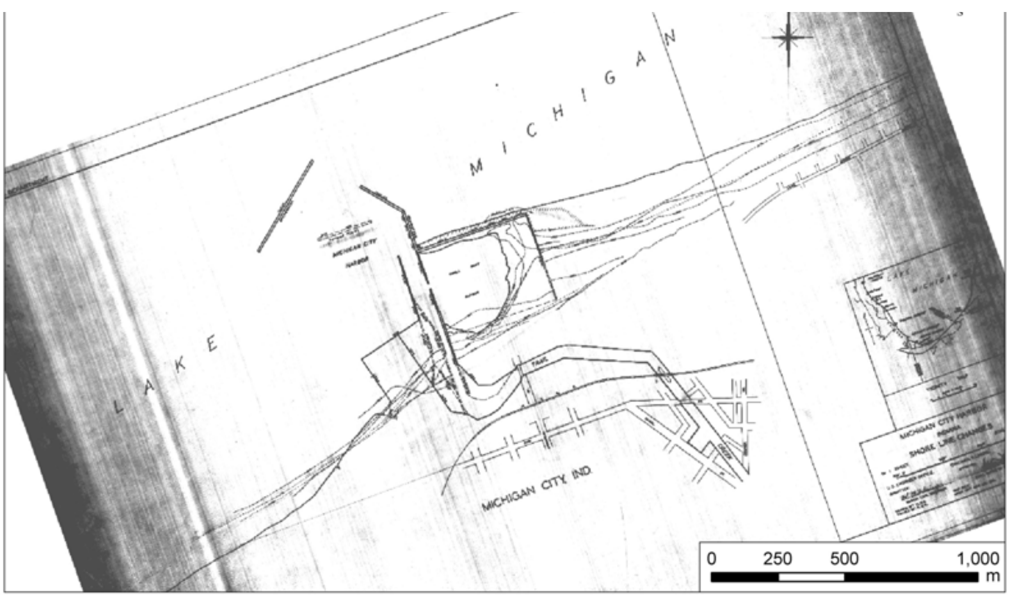


Figure 2.1.1.1-1 Historical Chart from 1938

2.1.1.2 SHOALS and NOAA Data

Several sources of bathymetric data were retrieved, processed, and converted to the proper horizontal and vertical datums for the study analysis. The USACE collected detailed bathymetry in the spring of 2004 using LIDAR technology, which utilizes an airborne sensor to collect very detailed bathymetric data in the nearshore. A sample of the 2004 SHOALS data, converted to a 3D grid, is presented for the Michigan City Harbor area in Figure 2.1.1.2-1. The soundings from the 1992 NOAA survey are also

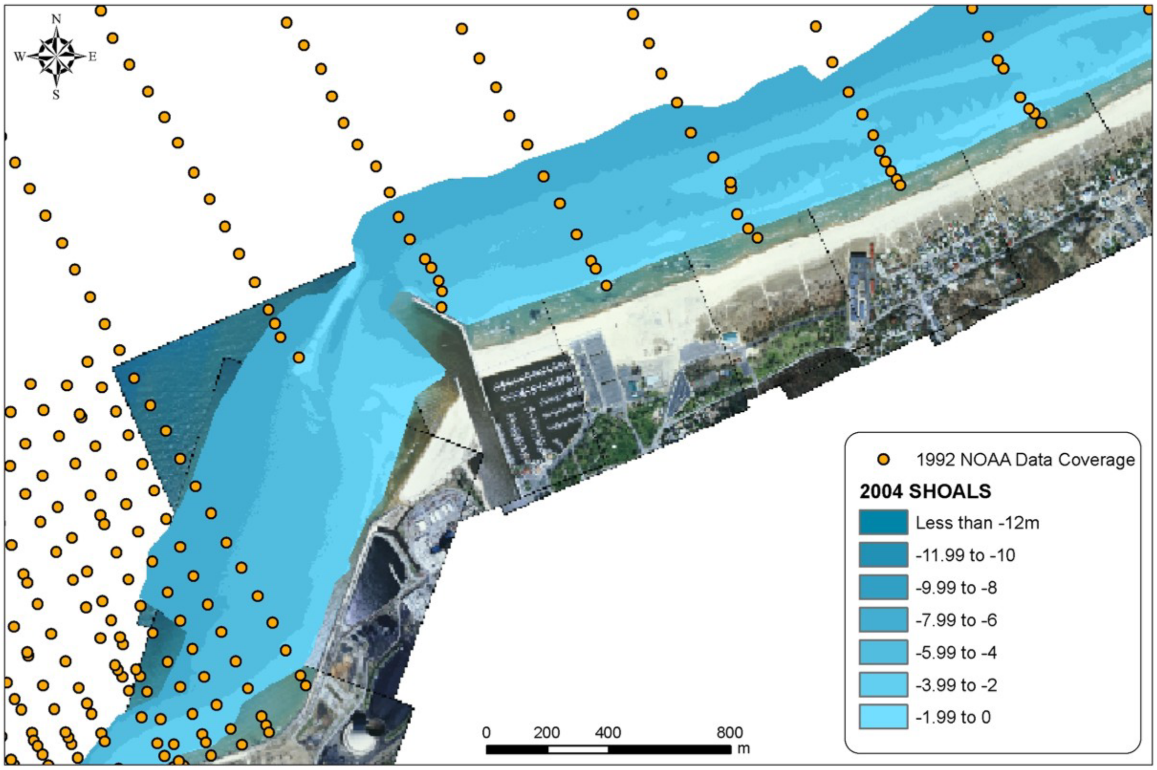


Figure 2.1.1.2-1 2004 SHOALS LIDAR Grid and 1992 NOAA Soundings

presented in Figure 2.1.1.2-1, for reference. Although the density of points is significantly reduced in comparison to the SHOALS data, the spatial coverage is very good and the 1992 bathymetry soundings provide an important record of the historical lake bed depths. Historical surveys from 1874, 1889, 1894, 1913, 1945, and 1948 were also utilized in the study.

2.1.2 Topography Data

Topographic data, or land elevations above the water, were collected from several sources and provided valuable data for the shoreline change analysis, such as volume calculations for the fillet beach. The sources are described below.

2.1.2.1 National Elevation Data (NED)

National elevation data (NED) is available from the USGS for the entire continental United States at various grid resolutions. A portion of the 10 m grid for the Michigan City Harbor is presented in Figure 2.1.2.1-1. Elevations are in meters, International Great Lakes Datum (IGLD) 1985. A portion of Trail Creek is visible, along with the Michigan City Marina basin and the high relic sand dunes south of the updrift (north) fillet beach. The NED data was used to supplement the topographic LIDAR discussed below, which didn't provide complete spatial coverage in all required locations for the study.

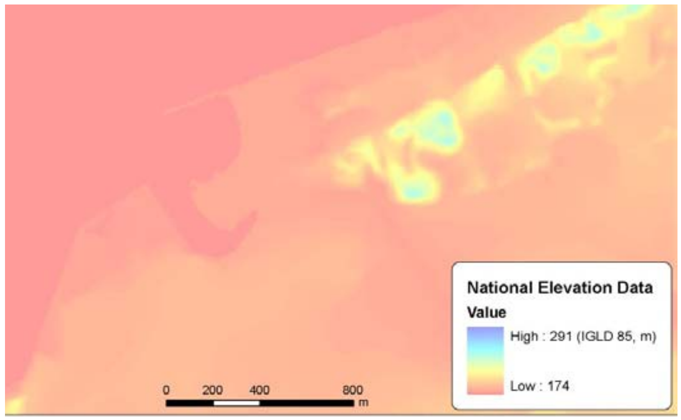


Figure 2.1.2.1-1

2.1.2.2 Topographic LIDAR

Topographic LIDAR was collected simultaneously with the bathymetric LIDAR along the coast of Michigan City. This dataset provided a detailed snap shot of the existing beach and dune conditions throughout the study area, as seen in Figure 2.1.2.2-1 below. Individual buildings are discernable, particularly on the NIPSCO grounds west of Trail Creek However, as also seen in the figure, the spatial coverage is not complete and in some locations the data was stitched together with the NED information, which provided complete coverage.

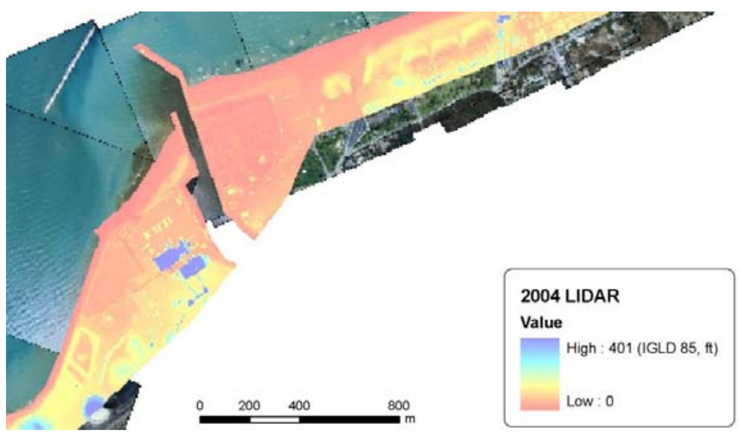


Figure 2.1.2.2-1

2.1.3 Aerial Photographs

Several aerial photographs were collected and generated for the study, as outlined in the following sections.

2.1.3.1 Recent Orthophotograph

An orthophotograph was available from 2003 for the entire extents of the study area from the Indiana Spatial Data Portal. The photo was taken during the "leaf on" period and had a pixel resolution of 1.0 m. This dataset was used as the backdrop for Figure 1.3-1.

2.1.3.2 Registration of 1938 and 2002 Photographs

Although the 2003 orthophotograph provided complete spatial coverage, the resolution was poor for the shoreline change analysis. Specifically, digitizing the historical dune crest line, vegetation line and waterline. Therefore, a series of 1:6,000 scale color images from 2002 were obtained from the Detroit District, scanned at a resolution of 1200 dots per inch (dpi) and then ortho-rectified with PCI Geomatica v9.1 OrthoEngine. The program uses a 3D data model of the topography during the registration process and provides superior results to simply stretching or warping images. A series of tiled 2002 images for the Mount Baldy area are presented in Figure 2.1.3.2-1.

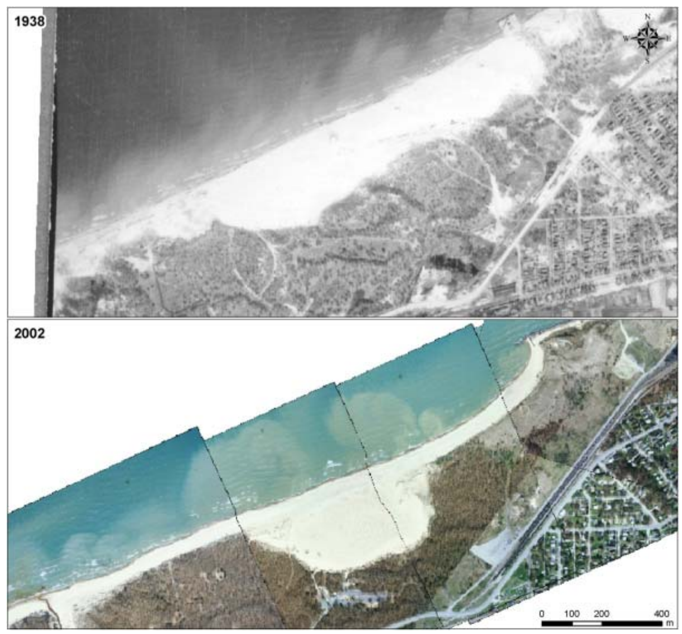


Figure 2.1.3.2-1 1938 and 2002 Orthophotographs

Historical 1938 aerials were also obtained from the Detroit District and registered (warped and stretched) using ArcGIS 9.x. Refer to the top panel in Figure 2.1.3.2-1. Combined, these two datasets provided the historical and contemporary information on the waterline, vegetation line and dune crest (were visible). The details of the shoreline change calculations are discussed in Section 3.3.

2.1.4 Sub-surface Data

A sub-surface investigation was completed at Michigan City by Ocean Surveys Inc. on August 21, 2003 to record lake bed depths and seismic reflectors. The nine profile lines are plotted in Figure 2.1.4-1 and discussed further in Section 3.0.

Figure 2.1.4-1 Sub-Surface Profiles

2.2 Temporal Data

The temporal datasets utilized for the study are summarized, including: hourly wave data, lake level gage data, ice cover time series, recorded river discharge data for Trial Creek, dredging and beach nourishment records and published recession rates.

2.2.1 Hourly Wave Data

Wave data was critical to the analysis of hydrodynamics and sediment transport in both a regional context and locally at the Michigan City Harbor. Hourly wind data was utilized from two wind stations, Chicago Airport and Milwaukee Airport, providing coverage from 1956 to 2000. For a complete description of the wind wave hindcast, refer to the letter report by Baird (2003).

2.2.2 Recorded Lake Level Data

The long term monthly mean lake levels for Lake Michigan were presented in Figure 1.5-1 for the period 1900 to present. This dataset provides a good overview of the long term trend in shoreline change rates, which can be significantly influenced by cycles or trends in lake levels (Zuzek et al, 2003). It was also used for the LST modeling.

2.2.3 Ice Cover Time Series

Historical nearshore ice cover data was collected for the entire shoreline during the Lake Michigan Potential Damages Study (Baird, 2001), from 1973 to 1997. The spatial data was converted to a daily time series record for each 1 km shoreline reach around the perimeter of the lake, then statistically extended to cover 1956 to 2000. The data at Michigan City was combined with the hourly waves and lake levels to generate a historical record for the sediment modeling.

2.2.4 River Discharge Data

Two sets of river discharge data were available for Trail Creek from the USGS. The first gage, #4095300, was located upstream of the harbor and provided data coverage from 1969 to 1994. From October 1994 to September 2003 gage #4095380 provided data much closer to the Michigan City Marina. Refer to Figure 2.2.4-1 for a plot of the daily mean stream flow from the two gages for Trail Creek.

A variety of sources were utilized to collect relevant information on the sediment yield from the Trail Creek watershed, which may ultimately influence the sedimentation processes along the coast. By the late 1800's, the majority of the watershed had been converted to agricultural lands, some with a forested buffer. Presently, the land use for the lower reaches of the watershed at Michigan City are predominantly urban. These land use changes, plus the loss of wetlands in the watershed likely results in higher peak flows or a flashier system. The likely contributors to sediment load are the agricultural lands and urban runoff. The soil types in the watershed include sandy loam, sandy silt and sandy/silty clay and contribute approximately 6,180 tons of sediment annually (USGS, 19xx).

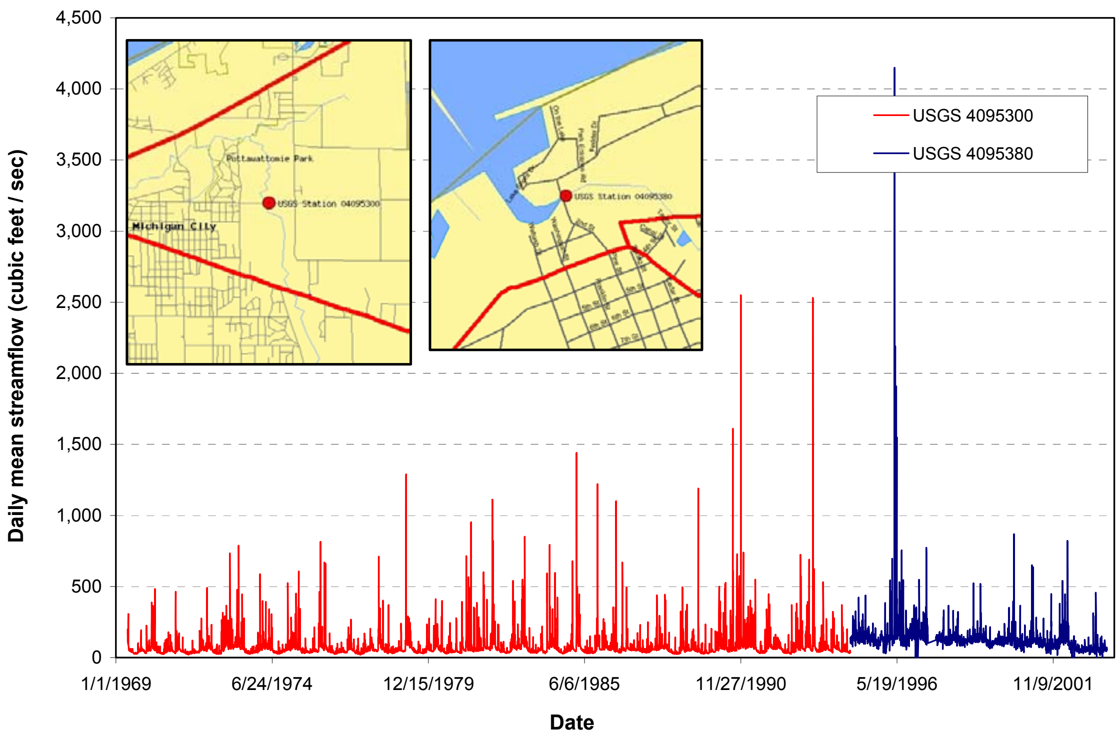


Figure 2.2.4-1 Daily Mean Discharge for Trail Creek (data from USGS)

2.2.5 Dredging and Nourishment Records

Dredging and beach nourishment records for Michigan City were assembled by the Chicago District from 1920 to 2000. Although the historical records provided the year and volume of sediment removed from the lake bed, they were not always specific on the location of the dredging. Consequently, the location of the dredging is categorized as either: inner harbor, outer harbor, combined inner and outer harbor or unknown. The results of this analysis are presented graphically for the period of 1920 to 2000 in Figure 2.2.5-1. The individual colored symbols indicate the location of the dredging, while the green line is the cumulative yearly total, regardless of location.

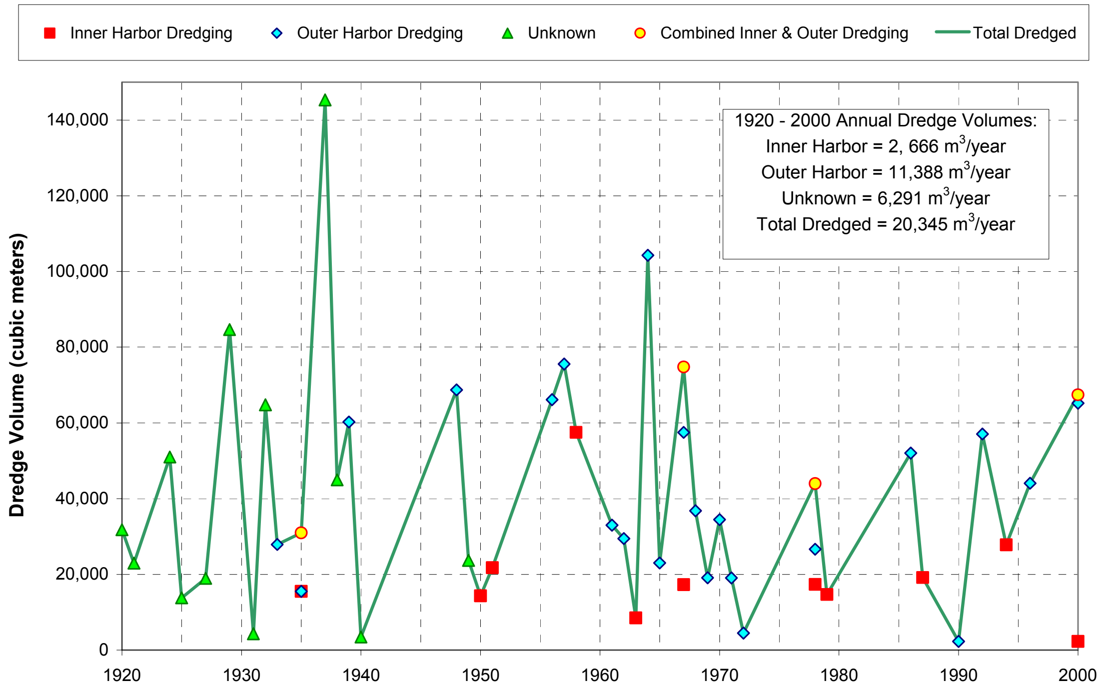


Figure 2.2.5-1 1920 to 2000 Dredging Records at Michigan City

The beaches fronting Mount Baldy have been nourished since 1974. A total of 476,127 cubic meters have been trucked to the site from upland sources and placed on the beach. In addition, 191,813 cubic meters of sediment dredged hydraulically from the Michigan City Harbor has been placed on the beach. When annualized, approximately 24,700 cubic meters has been placed since 1974. Regardless of these efforts to stabilize the shore, the beach and dune continue to erode at Mount Baldy.

Table 2.2.5-1
Nourishment Placed at Mount Baldy (cubic meters)

Year	Inland Source (Truck Transport)	Michigan City Harbor (Hydraulic Dredge)
1974	173,554	
1981	61,164	
1986		52,020
1992		57,068
1996	43,580	36,852
1997	55,813	
1998	81,807	
1999	27,524	
2000		45,873
2001	32,685	
Total	476,127	191,813

2.2.6 Published Recession Rates

An extensive database of published recession rates for the shores of Lake Michigan was gathered for the Lake Michigan Potential Damages Study (Baird, 2001). The information was organized into the 1 km shoreline reaches developed for the study. It is important to note that the data was originally gathered and published by a variety of entities, with disparate techniques and different goals for the end product. In addition, the temporal duration of the measurements range from a few years to more than a century. Most importantly, the shoreline conditions have often changed significantly in the last few decade due to construction of shore parallel engineering structures and evolution of the harbor fillet beaches and bypassing shoal. Consequently, the published data is not likely indicative of the future erosion trends or suitable to calculate the volume of material erosion contributes to the sediment budget.

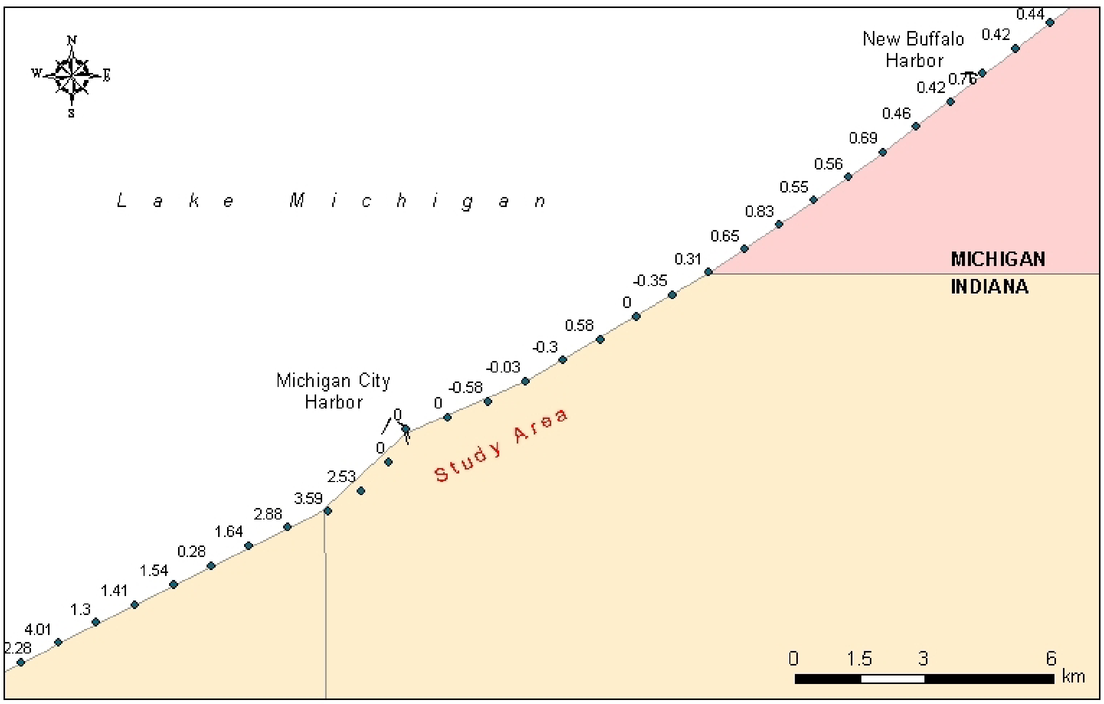


Figure 2.2.6 Published Average Annual Recession Rates for Study Area in meters per year (source: LMPDS)

3.0 SHORELINE CHANGE ANALYSIS

Section 3.0 of the report will summarize the shoreline change analysis completed for the study. The evolution of the shoreline at the harbor is discussed in Section 3.1.

3.1 Historic Shorelines at Harbor

Figure 3.1-1 summarizes the historical shorelines compiled at the Michigan City Harbor for the study. The majority of the historical shorelines were extracted from charts and maps obtained from the National Archives.

North of Trail Creek, the first historical shoreline at Michigan City was 1834, which was prior to any harbor structures. The yellow line in Figure 3.1-1 records the natural position of the shore adjacent to Trial Creek. Between 1834 and 1971, several surveys indicate the shoreline was stable and not migrating. The 1882 shoreline records the lakeward migration of the shoreline north of Trail Creek. Although the east breakwater was not completed until 1884, it is plausible the construction took several years and that even during construction the breakwater had an impact on deposition rates.

In 1884 the East Breakwater was complete. By 1890 the updrift fillet beach had migrated almost 200 m lakeward from the 1834 shoreline, which indicates as significant volume of sand was trapped in the fillet beach. The 1891 shoreline records the development of a large tombolo behind the East Breakwater. Interestingly, the limit of this sandy feature defines the Michigan City Marina basin, which is either a coincidence or planned opportunity. The 1894 shoreline indicates east breakwater was influencing fillet beach growth for approximately 1 km to the North-East. Between 1894 and 1939, the updrift fillet beach continued to trap sediment and was now adjacent to the east breakwater, which is 400 m lakeward of the pre-harbor shoreline. From the late 1930s to present, the fillet beach has continued to grow, however, at a much slower rate. This reduction in sediment accumulation is expected as the shoreline responds to the harbor structures.

Downdrift of Trail Creek, the trend in shoreline position was much different than updrift. The 1834, 1863 and 1874 shorelines in Figure 3.1 record the pre-harbor shoreline conditions and represent the base condition for the analysis. The first extensive shoreline following the construction of the East Breakwater is 1896 and it does record some downdrift erosion between 1874 and 1896. Following the construction of the West Pier in 1909, the 1913 and 1944 shorelines record the steady retreat of the beach. Between 1944 and 1969 the shoreline orientation was altered and armored for the NIPSCO plant. The downdrift beaches fronting Mount Baldy continued to retreat during this period based on the historical shorelines.

Figure 3.1-1 Historical Shorelines at the Michigan City Harbor

3.2 Regional Changes in Shoreline Position – 1874 to 2002

Calculating accurate long term shoreline change rates for the regional study area is challenging for two reasons. First, the back-beach and dune environment has undergone significant modifications along much of the shore due to residential development and shoreline protection structures. Consequently, in some locations it is not possible to generate accurate shoreline change rates when comparing the somewhat natural conditions in the 1800's to the highly altered shoreline conditions today. Second, the natural vegetation line, which is a common shoreline change reference feature for dune environments, is difficult to interpret in some locations from the 1938 aerial photographs and this feature is absent along some sections of the shoreline today due to the high degree of shoreline armoring. Therefore, the digitized waterline position from three temporal periods was compared to provide a second data set for the analysis. The three shorelines and associated area calculations at the harbor are presented in Figure 3.2-1.

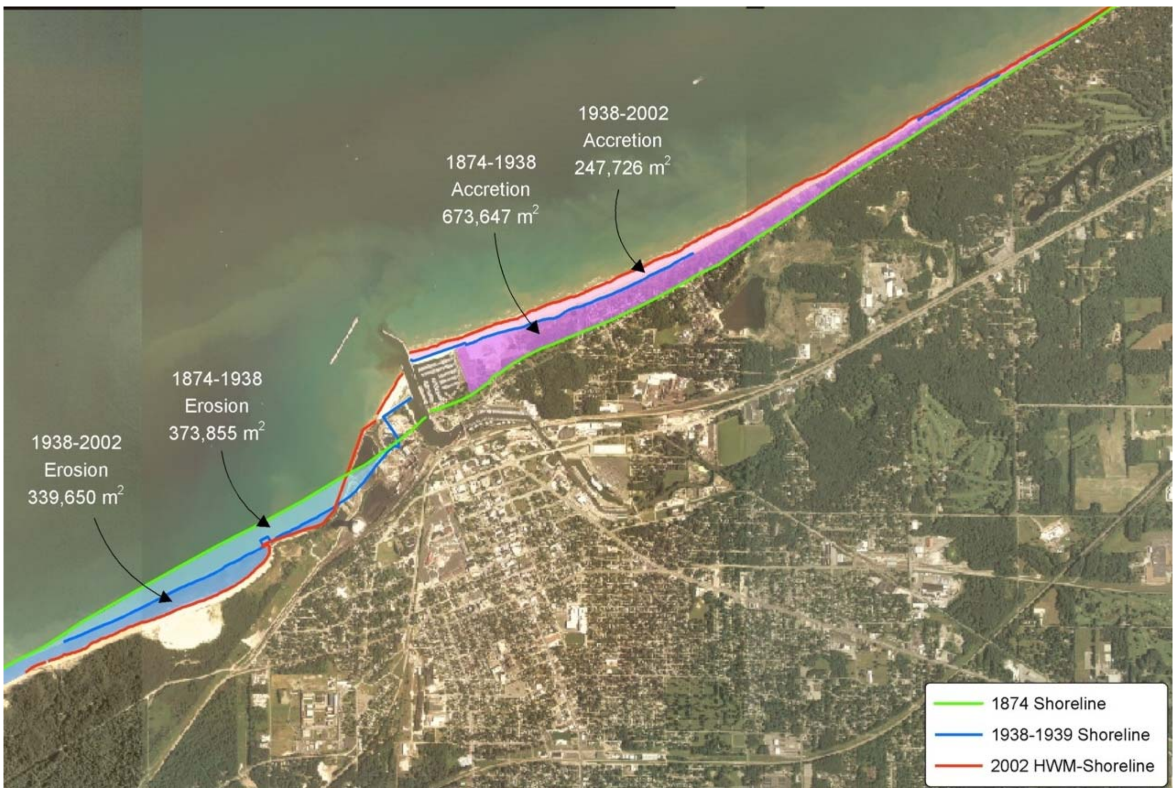


Figure 3.2-1 Historical Shorelines at the Michigan City Harbor

The 1874 shoreline interpreted from the historical chart is presented in green. Between 1874 and 1938 the surface area of the updrift fillet beach increased by 673,647 m^2, as seen by the pink shading in Figure 3.2-1. Between 1938 and 2002, the rate of deposition in the fillet beach decreased significantly, as only 247,726 m^2 of new beach was added. When these grow rates for the beach are annualized, the 1874 to 1938 period represents 10,364 m^2/yr, while the 1938 to 2002 period only saw the east fillet beach increase in area by 3,811 m^2/yr. These findings suggest the east fillet beach storage capacity has decreased significantly and is possibly reaching its maximum.

Downdrift of the Michigan City Harbor, the rate of beach area loss has been relatively consistent over the last 130 years as seen in Figure 3.2-1. For example, from 1874 to 1938, total loss in beach area was 373,875 m^2. When annualized, this loss rate represents 5,752 m^2/yr. Between 1938 and 2002 the numbers didn't change significant, with 339,650 m2 of beach loss, which converts to 5,225 m^2/yr.

There are several interesting observations that can be inferred from this data, which are summarized in the bullets:

- The fillet beach is reaching its maximum storage capacity, which may increase the potential for sediment bypassing south of the harbor,

- If the capacity of the fillet beach is decreasing, maintenance dredging requirements for the navigation channels may increase in the future as more sediment bypasses the East breakwater and offshore breakwater,

- There has been a small decrease in the rate of beach loss south of the harbor from 1938 to 2002. This may suggest the natural bypassing rate is increasing or the beach nourishment activities since the early 1970s have decreased the rate of erosion for the beaches in the Mount Baldy area.

Figure 3.2-2 provides a regional summary of the shoreline comparisons between 1938 and 2002. This temporal period was selected as it was more representative of the current trends than the 1874 to 1938 period. The shoreline has been sub-divided into three zones based on the observed changes in the beach width. From New Buffalo to the south-west, a x km zone of shore is classified as erosional. The reduction in beach area between 1938 and 2002 was 144,674 m^2. This region of the shore generally corresponds to Reach 1 in Figure 1.5.1-1.

The Michiana Shores segment of the coast has been classified as stable, as no measurable changes in the shoreline position were noted between 1938 and 2002. This area corresponds to Reach 2 in Figure 1.5.2-1. Conversely, the community of Duneland Beach featured an accretion trend, with a small increase in beach area of 17,318 m^2. Duneland Beach is also in Reach 2.

Not surprising, the updrift fillet beach, which is Reach 3 in Figure 1.5.2-1, featured a significant increase in beach area of 247,726 m^2. As mentioned, although the fillet beach featured an accretion trend, the rate of deposition appears to have slowed in comparison to the pre- 1938 period.

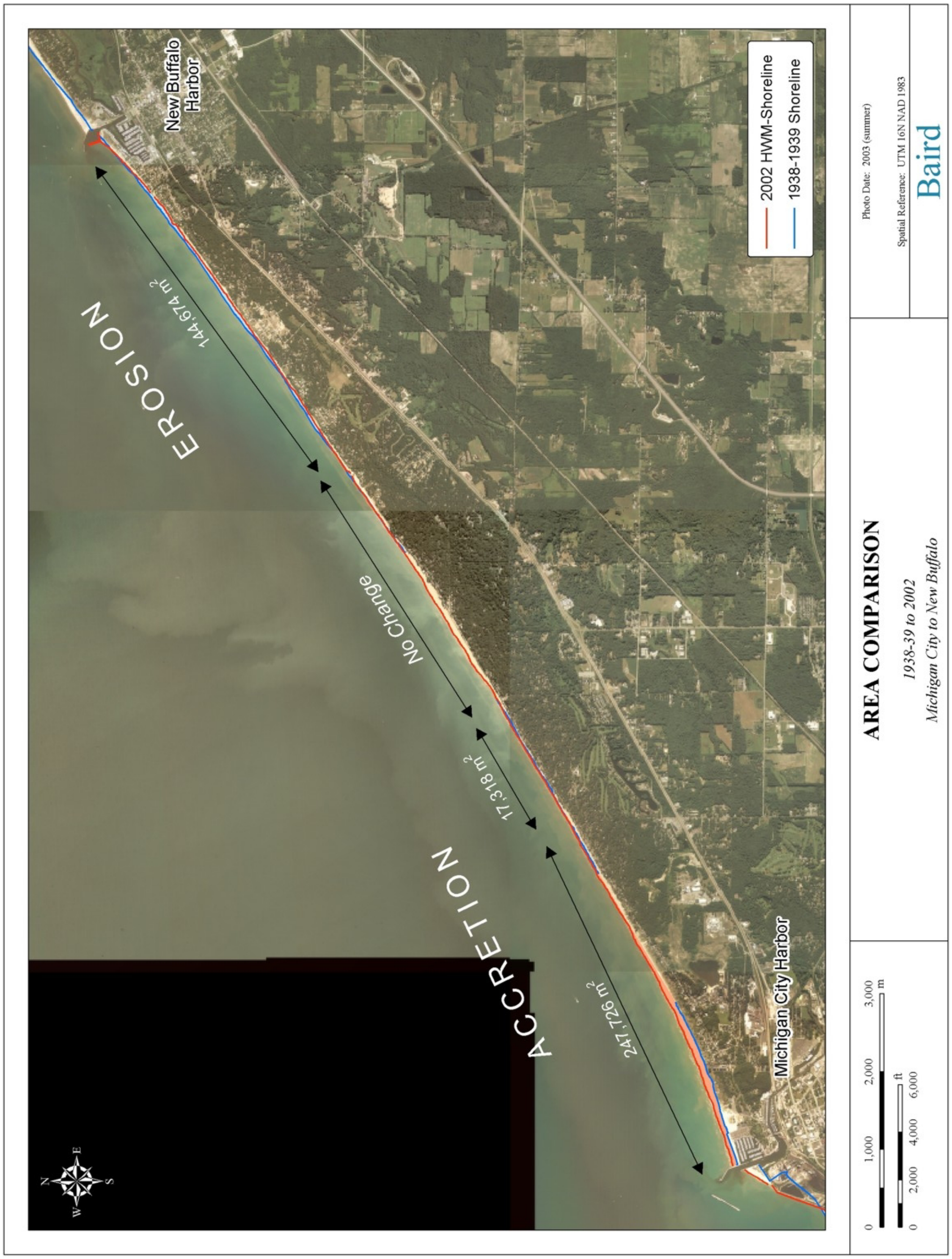


Figure 3.2-2 Regional Changes in Beach Area from 1938 to 2002

3.3 Calculated AARR – 1938 to 2002

The 1938 and 2002 orthophotographs were reviewed to select and digitize an appropriate shoreline change reference feature (SCRF) for the recession rate calculations. Since the digitizing would be done directly from the computer screen without the aid of a 3D environment, the dune crest line could not be accurately identified. Therefore the vegetation line or active limit of dune vegetation was selected as the SCRF. These lines are seen in Figure 3.3-1 below for the shore immediately downdrift of the New Buffalo Harbor. In the bottom panel, the blue line traces the position of the vegetation line in

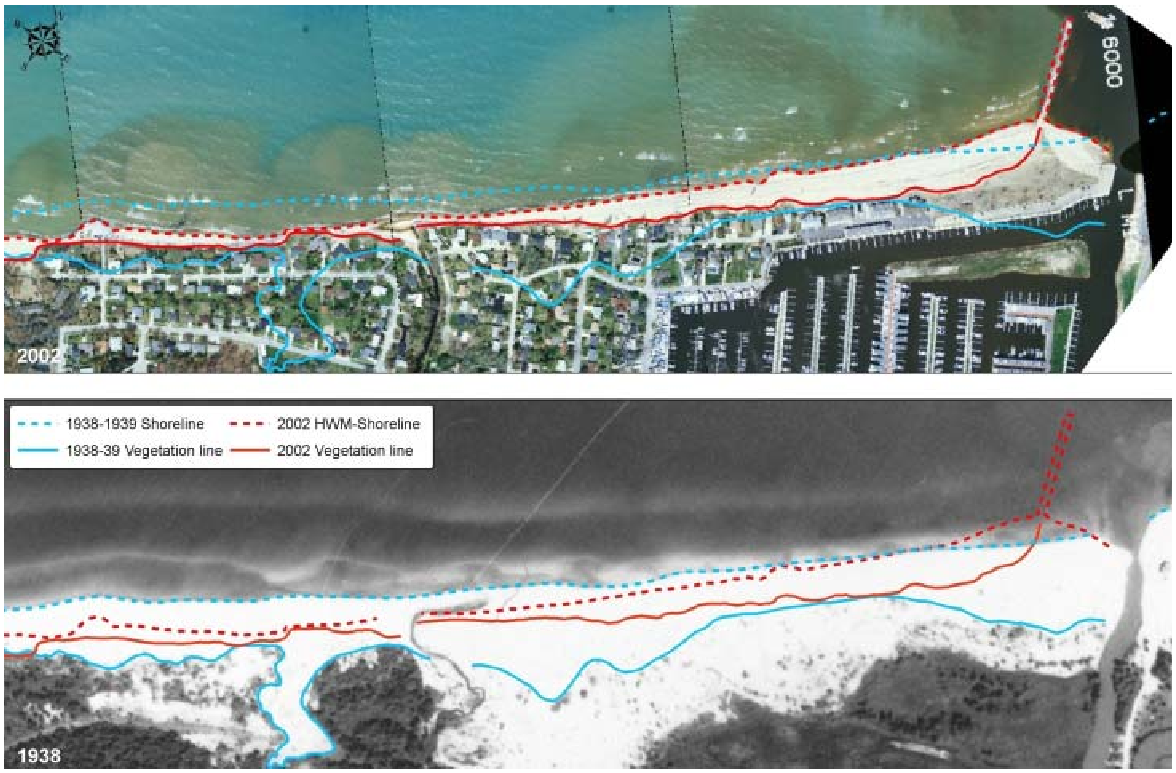


Figure 3.3-1 1938 and 2002 Shorelines and Vegetation Lines

1938, which is quite irregular as this was once a natural dune environment. In the 2002 photo (top panel), the vegetation line is traced in red. If transects were measured between the two vegetation lines in the 1938 panel, they would record a significant accretion trend. However, this is not due to natural processes but rather modifications to the natural dune environment to support high density residential development. Therefore, erosion measurements were not completed for this region immediately downdrift of the harbor as the results would not be representative of the actual trend, which appears to be erosion.

This type of scrutiny was completed for the entire length of the study area to ensure the shoreline change rates were accurate and recorded the proper trend. Interestingly, the two waterlines seen in the bottom panel document a reduction in the beach area directly south of the harbor, which identifies the most probable trend for this shoreline.

Figure 3.3-2 provides the results of a similar comparison between the 1938 and 2002 shoreline and vegetation lines at Mount Baldy, downdrift of the Michigan City Harbor, which corresponds to Reach 5. For this particular reach, both the waterlines and vegetation lines correctly record the long term shoreline trend, which is severe erosion. The location of the NIPSCO revetment can be seen in the 2002 orthophotograph. West of the revetment, there has been some advancement in the vegetation line, likely due to the shoreline stability associated with the structure. The Mount Baldy parabolic dune has experienced a significant retreat of both the shoreline and vegetation line, as seen in Figure 3.3-2.

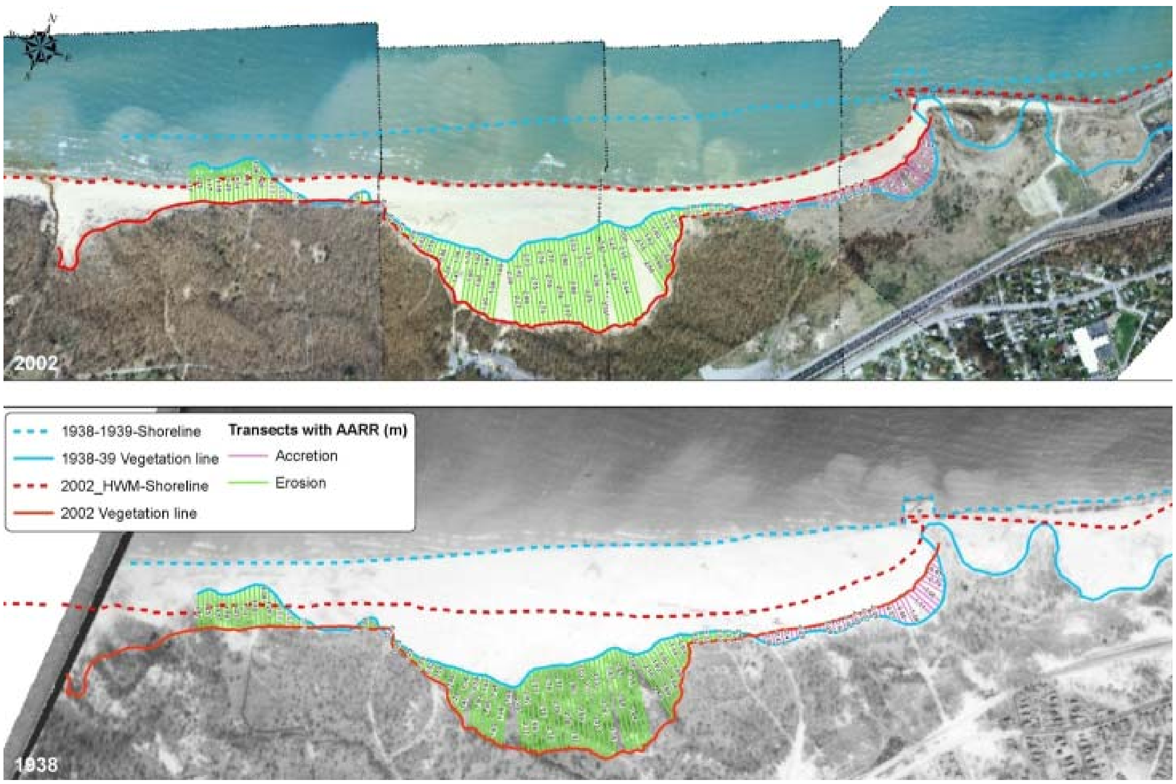


Figure 3.3-2 1938 and 2002 Shorelines and Vegetation Lines at Mount Baldy

Shoreline change rates were calculated for the study area from New Buffalo South-west to the Beverly Shores revetment. In some locations, the 1938 aerial photographs were not available and consequently the measurements are not continuous, as seen in Figure 3.3-3.

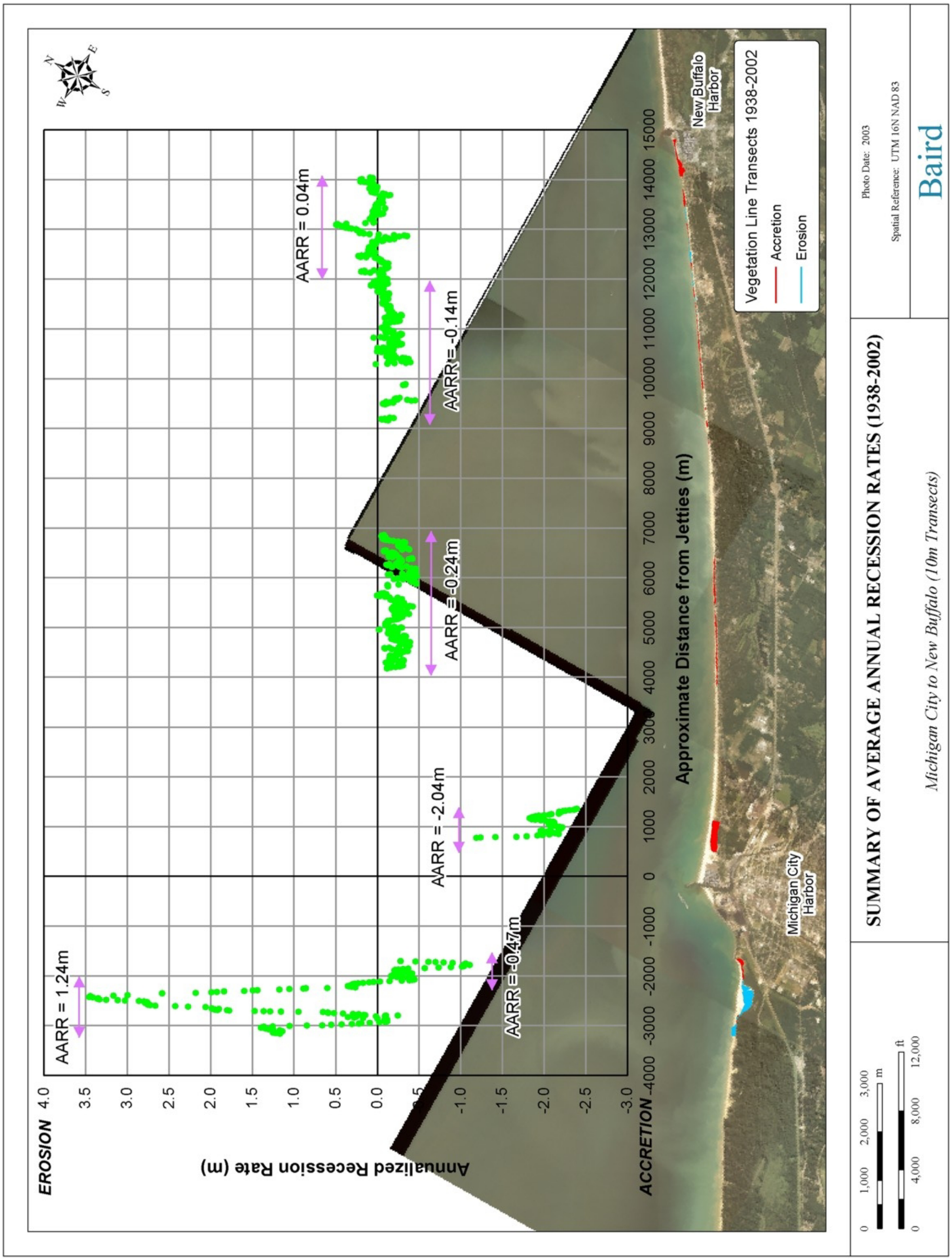


Figure 3.3-3 1938 to 2002 Shoreline Change Rates Based on Vegetation Line

For the first three km south-west of New Buffalo, there is consider scatter in the recession rates. However, the average trend is a small recession rate, as the AARR is only 0.04 m/yr. A cluster of measurements in the Grand Beach area document a long term accretion trend, with an AARR of 0.14 m/yr. Photographs 6 through 8 in Figure 1.5.1-1 document the shoreline conditions in this area, which is highly modified by the residential development and construction of shoreline protection. Therefore, it is possibly the Grand Beach accretion trend is influenced by the construction of engineering structures.

There is a third cluster of transect measurements that correspond to the Duneland Beach and Long Beach communities. The average annual shoreline change rate is 0.24 m/yr of accretion. This trend corresponds well with the beach area calculations, which indicate this area is either stable or accreting.

The available 1938 to 2002 comparison for the updrift fillet beach North-west of the marina indicates the long term trend is an accretion rate of 2 m/yr. This corresponds well with the calculated beach area changes and the expected condition for the fillet beach.

No shoreline change calculations were completed for Reach 4, which corresponds to the harbor region and the associated engineering structures. For Reach 5, approximately 1.5 km of transects were measured between the 1938 and 2002 vegetation lines. With the exception of a small area immediately in the shadow of the NIPSCO seawall, the long term trend is erosion. The rates reach a maximum of 3.5 m/yr for the center of the parabola at Mount Baldy, while the average for this region is 0.47 m/yr.

In summary, the trends for the shoreline change rates calculated between 1938 and 2002 generally correspond to the beach area calculations and the classification of the shoreline in Figure 3.2-2.

3.4 Bathymetry Comparisons

The first 3D bathymetry comparison utilized a detailed 1889 survey in the vicinity of the Michigan City Harbor. This historical bathymetry was compared to the site conditions in 1913, approximately 25 years later. It is worth noting that some gaps in the 1913 survey were filled with data from 1894.

Depositional rates along the updrift fillet beach and in the nearshore zone ranged from 0 to 3.0 m over this 25 year period (Figure 3.4-1). Further offshore, the bathymetry comparison records the growth of a large bypassing shoal centered on the offshore breakwater. Deposition ranged from 2 to 4 m, with the highest accumulation occurring between the east jetty and offshore breakwater.

The other region with a high rate of deposition is the lake bottom adjacent to the west jetty, were the sedimentation rates vary from 2 to 3 m for the 25 year period. Offshore of

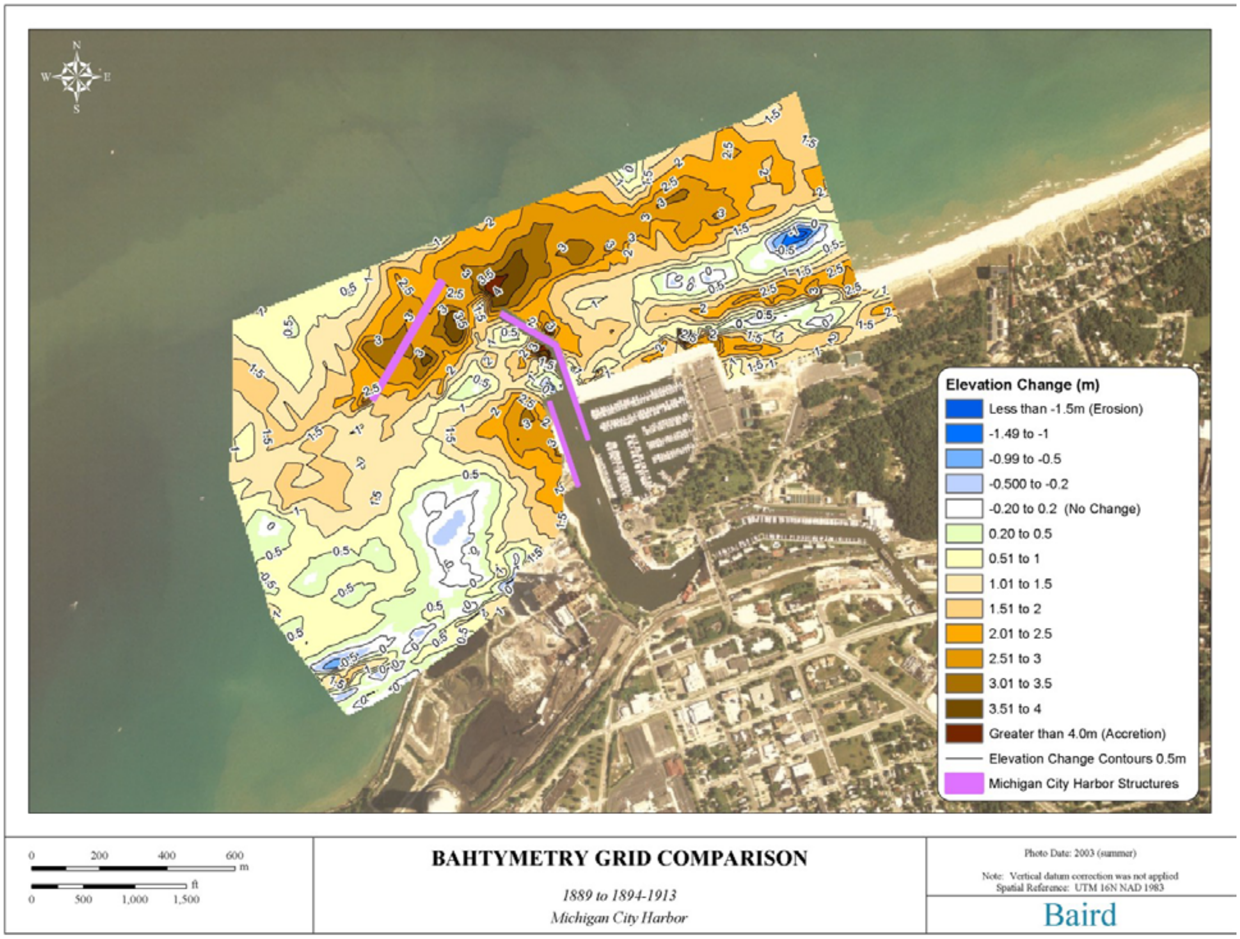


Figure 3.4-1 1889 to 1894/1913 Bathymetry Comparison

the NIPSCO plant, the lake bed was generally stable or experience a minor depositional rate of 0.5 m/yr.

A second bathymetry comparison is provided in Figure 3.4-2 for the period spanning 1889 to 2004, which is covers a 116 year period. The shaded contours of change in the figure provide a mature summary of the harbor impacts on the lake bed. For example, deposition in the dry portion of the fillet beach ranges from 4 to 13 m. Deposition for the lake bed offshore of the fillet beach ranged from 2 to 3 m. For the bypassing shoal, the deposition ranged from 4 to 5 m.

Between 1889 and 2004 there has been significant growth of the downdrift or west fillet beach, as seen in the bathymetry comparison of Figure 3.4-2. Deposition rates range from 3 to 5 m for the lake bed, and up to 10 m for the dry portion of the fillet deposit. Beyond the shadow of the offshore breakwater, depositional rates decrease significantly and range from 1 to 2 m. There is also a clear transition from sedimentation to erosion marked by the 0 m contour offshore of the NIPSCO seawall. In fact, lake bed downcutting rates of up to 3 m are recorded close to shore.

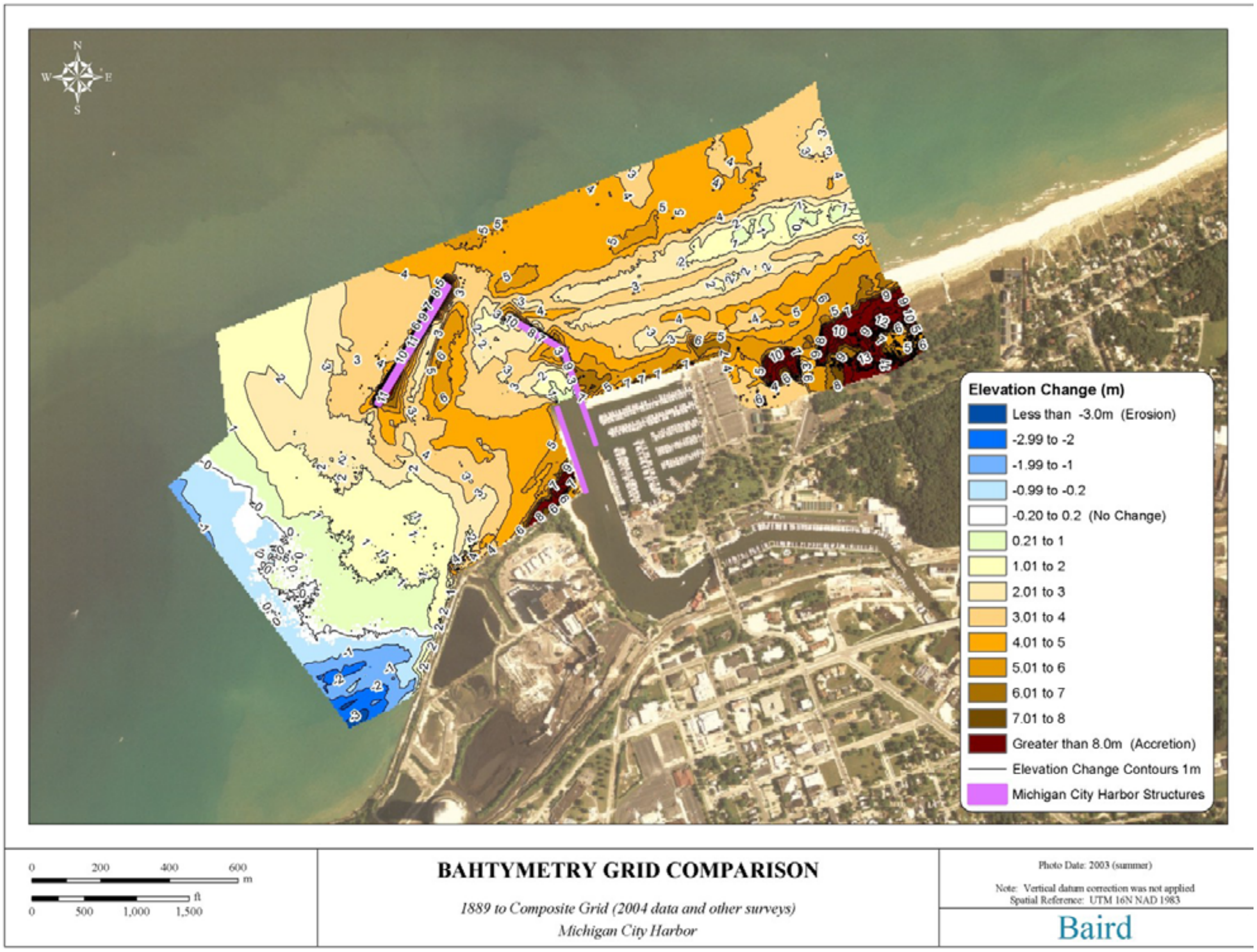


Figure 3.4-2 1889 to 2004 Bathymetry Comparison

In summary, the bathymetry comparisons record significant changes in the lake bed depths at the Michigan City Harbor, particularly in the updrift fillet beach and bypassing shoal. The west fillet beach has also grown significantly in the last 100 years. Figure 3.4-2 clearly identifies the limits of lake bed deposition associated with the harbor structures as noted by the 0.0 m contour.

3.5 Bypassing Shoal

The spatial extents of the bypassing shoal can be inferred from the bathymetry comparison in Figure 3.4-1 and includes the lake bed surrounding the offshore breakwater and further to the east. Figure 3.5-1 identifies the locations of three profile comparisons completed to quantify the depositional rates for the shoal over time. Profile

A commences offshore of the updrift fillet beach and continues in a South-west direction, with the offshore breakwater located to the south. Changes in the lake bed position over time at Profile A are plotted in Figure 3.5-2. The first reliable bathymetric dataset is 1884 and is plotted in green. Interestingly, this dataset may have captured the location of a paleo-channel associated with a previous low water stage on Lake Michigan, such as the Chippawa Low (xx, 19xx). Between 1894 and 1944 the entire feature increased is size, as seen in the orange line. Following the 1944 period, the downdrift side of the shoal has been fairly stable with little or no accumulation of sediment. The updrift side of the shoal did grow between the 1944 and 1969 period, however, the 1992 profile indicates that following 1969 the feature has been relatively stable in size and form. It is possible the feature continues to grow beyond the limits of our profile comparison, such as in deeper water. Profiles B and C are provided in Appendix A and show similar trends.

Figure 3.5-1 Profiles of Bypassing Shoal

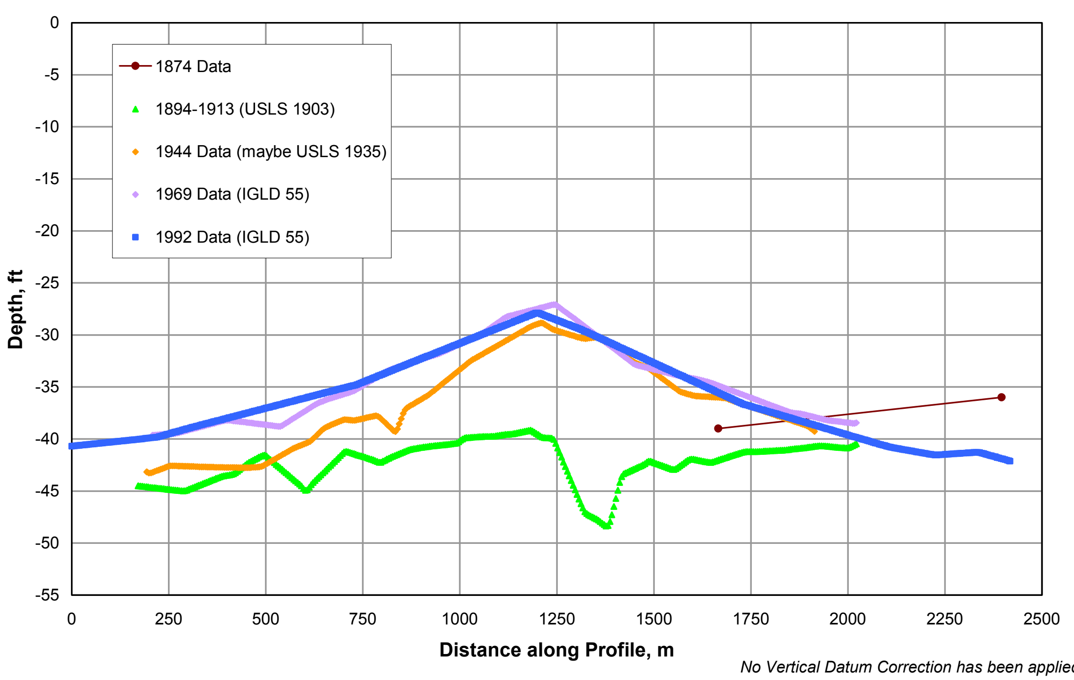


Figure 3.5-2 Comparison of Lake Bed Conditions a Profile A

3.6 Profile Comparisons

Section 3.6 of the report will describe additional profile comparisons for three critical areas, including downdrift of New Buffalo, the updrift fillet beach at Michigan City and the downdrift fillet beach, including the lakebed offshore of the Indiana Dunes National Lakeshore. They are described individually below.

3.6.1 Lake Bed Profile Comparisons Downdrift of the New Buffalo Harbor

A series of four profile comparisons were completed for the downdrift shoreline at New Buffalo. Figure 3.6.1-1 plots the location of the profiles, which commence at the Dunewood Development (Profile A) and end at Grand Beach.

Figure 3.6.1-1 Profiles Downdrift of New Buffalo

The results for Profile A are presented in Figure 3.6.1-2 and include data from 1874 to present. The 1874 data is coarse and only presented as points, as it wasn't possible to generate a grid. Between 1874 and 1945 there was a depositional trend for Profile A from the waterline to approximately the 7 m depth contour. From 1945 to 1992, the bathymetry data suggests a trend reversal, as the profile records erosion from the waterline to a depth of approximately 7 m. Using the detailed SHOALS dataset, the 1992 to 2004 period also

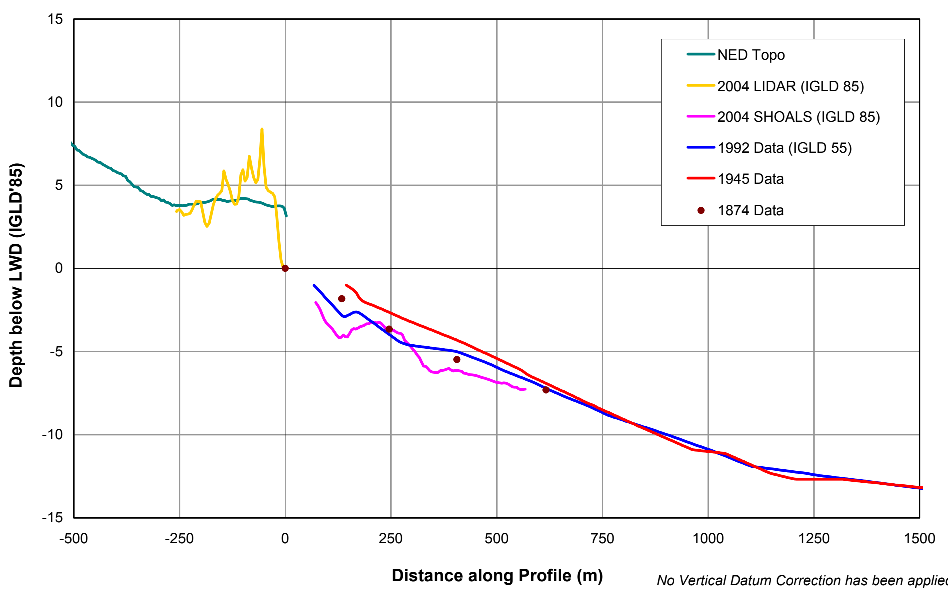


Figure 3.6.1-2 Profile Comparison at Profile A (depths in m)

records profile erosion to approximately the 6 m depth contour. The difference in the resolution between the topographic LIDAR and the 10 m NED data is seen for the portion of the shoreline above low water datum (LWD).

A similar trend reversal was recorded following the 1945 survey at Profiles B and C. At Profile D, the trend reversal didn't occur until after the 1992 survey, suggesting the nearshore erosion hotspot is migrating downdrift. Profiles B through D are provided in Appendix A.

3.6.2 Lake Bed Profile Comparisons for Updrift Fillet Beach

A total of seven lake bed profile comparisons were completed for the north fillet beach at Michigan City. The oldest dataset used in the analysis was the 1874 bathymetry, which corresponds to the pre-harbor condition. Figure 3.6.2-1 presents the location of the profiles for the East fillet beach. The different snap shots of lake bed bathymetry for Profile B are presented in Figure 3.6.2-2. The 1874 profile plotted in black was surveyed prior to the construction of the east breakwater, which was finished in 1884. The 1889 and 1894 record significant deposition for the ten years following the construction of the first structure at Michigan City. The 1894 survey is followed by the 1945 and 1948 profiles, both of which record deposition in the nearshore zone and match well with the older

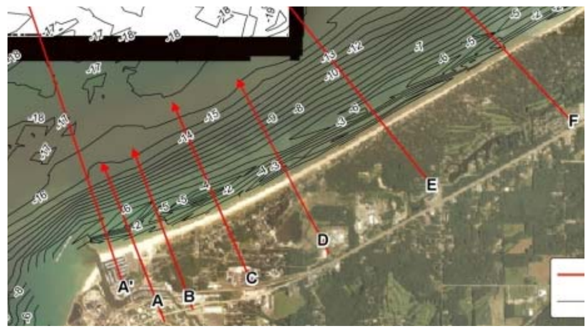


Figure 3.6.2-1 East Fillet Beach Profiles

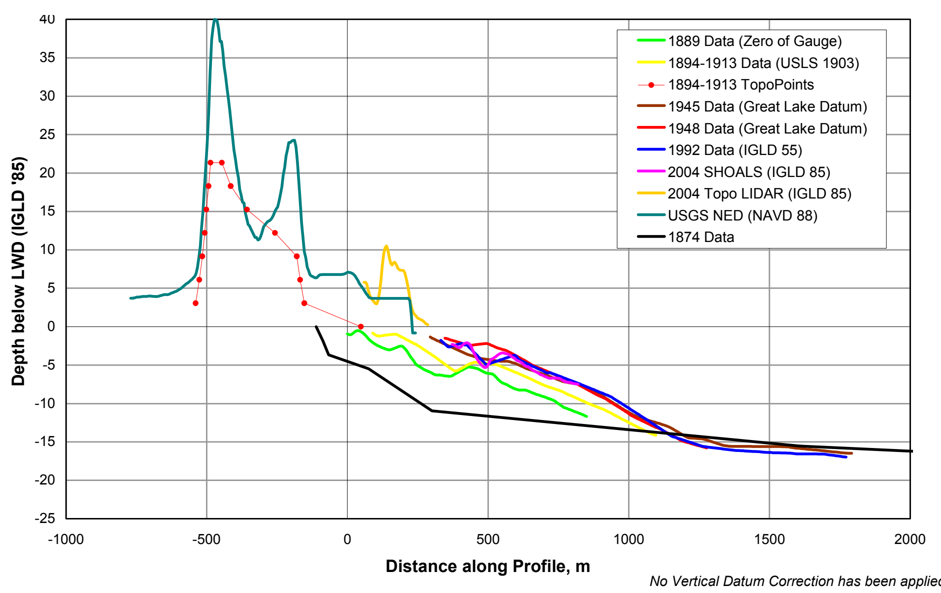


Figure 3.6.2-2 Bathymetry Comparison at Profile B (depths in m)

surveys in depths greater than 13 m. With additional data resolution, the 1992 and 2004 profiles appear to record the position of a bar and trough in the nearshore zone. Beyond the 5 m depth contour, they match well with the previous surveys. In general, it appears the rate of deposition on the lake bed at Profile B has decreased significantly since 1945.

The historical position of the beach and dune crest is presented in Figure 3.6.2-2 based on the 1894 survey. When compared to the USGS NED, which is a current dataset, the dunes have grown significantly in height in the last 100 years. The 2004 topographic LIDAR captures the beach and foredune with high resolution data, which may explain the difference between the LIDAR and NED elevations.

The results of the bathymetry comparison at Profile D are summarized in Figure 3.6.2-3. As previous, the 1874 profile represents the pre-harbor condition. Lake bed deposition continued until 1948, as the red profile line indicates. The 1992 and 2004 lines match the

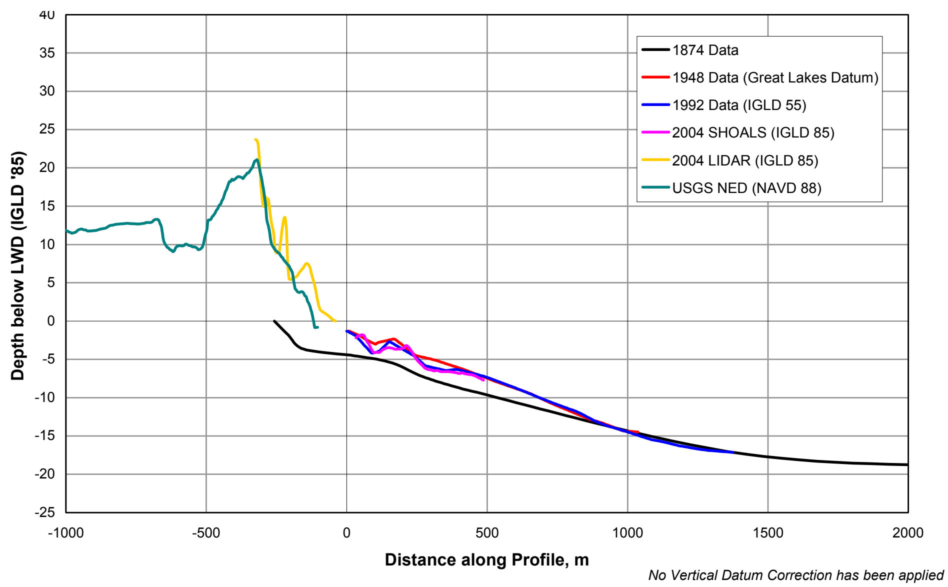


Figure 3.6.2-3 Bathymetry Comparison at Profile D

1945 condition very well, especially below the 5 m depth contour. Between the shoreline and 5 m depth, bar and trough migration due to water level fluctuations may explain the differences in Figure 3.6.2-3 for the 1948 to 2004 bathymetry.

The remaining profiles for the updrift fillet beach are presented in Appendix A.

3.6.3 Lake Bed Profile Comparisons Downdrift of the Harbor

A total of ten profiles were generated south of the Michigan City Harbor. The locations are noted on Figure 3.6.3-1, with data coverage from 1874 to 2004. Profile C records changes to the lake bottom offshore of the NIPSCO seawall, as seen in Figure 3.6.3-2.

Between 1874 and 1889, the profile was relatively stable and there appears to be little, if any influence by the harbor at this time. This was prior to the construction of the west pier, which was completed in 1909. The composite 1894-1913 records lake bed deposition between the –2 and –10 m depth contour. This accumulation may be associated with the newly constructed west pier and/or the offshore breakwater, which was finished in 1903.

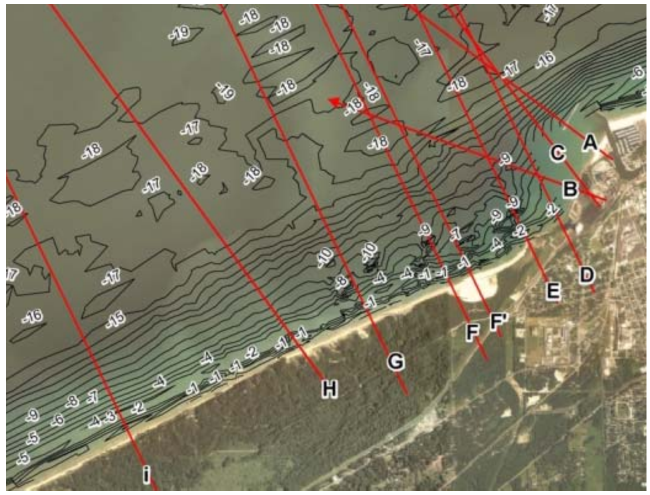


Figure 3.6.3-1 Downdrift Beach Profiles

Modifications to the NIPSCO lands occurred some time after 1944 and were completed before 1969, based on our analysis of the historical aerial photographs and maps. At Profile C, lake filling extended the shoreline into the lake, as recorded by the topographic data in Figure 3.6.3-2 (NED and SHOALS profiles). This reach of shore is now protected with a steel sheet pile wall and revetment. The 1992 and 2004 profiles for Profile C indicate there has been a small amount of additional lake bed deposition associated with the lake filling.

Profile F' was located in the center of the parabolic dune at Mount Baldy. Although the

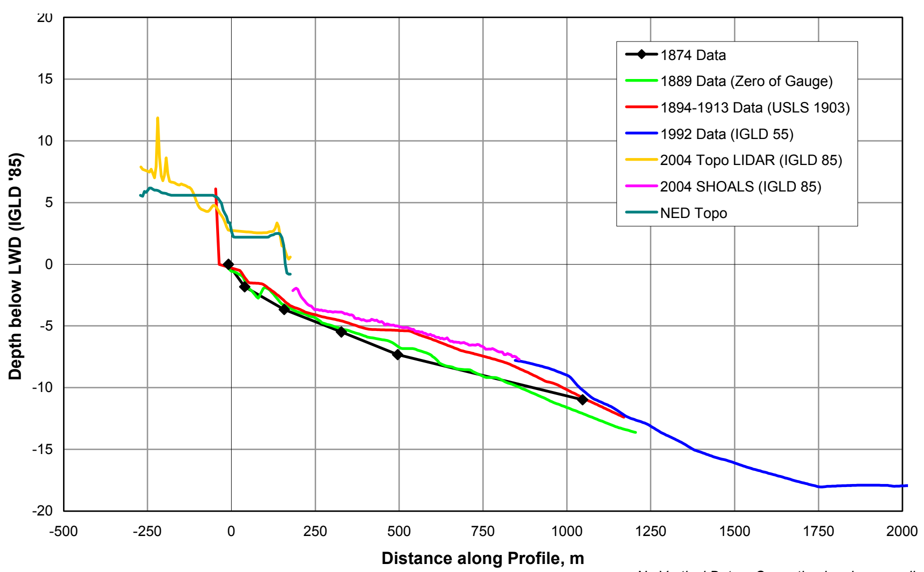


Figure 3.6.3-2 Bathymetry Comparison at Profile C

historical sources of bathymetry are limited to the 1874 data, it documents the downdrift erosion that has occurred at the site over the last 130 years. When compared to the 1992 and 2004 profiles, significant lake bed erosion has occurred. In addition, the zero contour from 1874 to 2004 has retreated approximately 250 m. The comparison between the NED and topographic LIDAR documents the retreat of the Mount Baldy dune (date of NED unknown).

The profile change for F' is representative of the lake bed changes recorded at Profile F

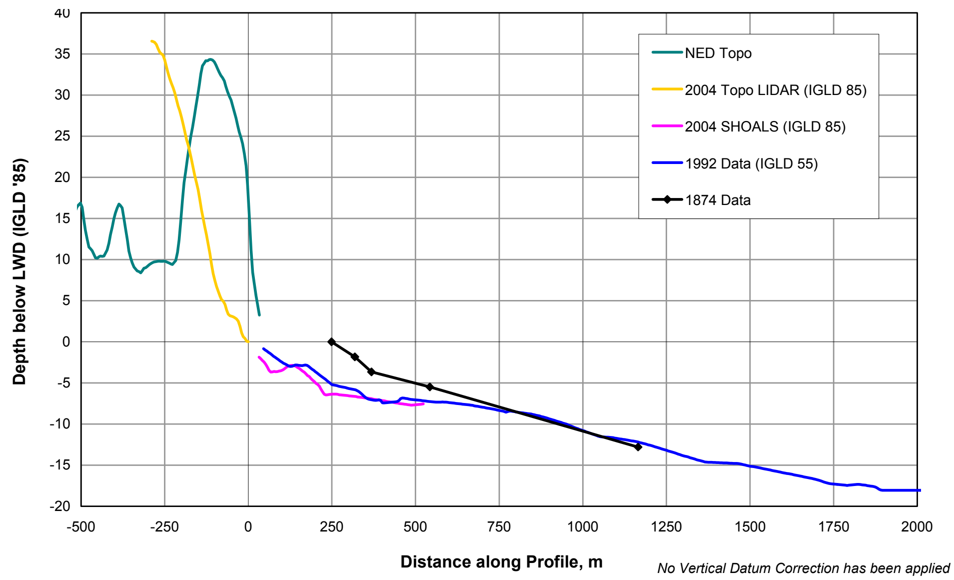


Figure 3.6.3-3 Bathymetry Comparison at Profile F'

and H. However, at Profile I, which is located along the Beverly Shores revetment built in 1974, the picture is quite different. The lake bed depths have not changed since 1874, as documented in Figure 3.6.3-4. There is a surprisingly good match between the 1874, 1992 and 2004 Profiles. The results suggest this profile is located in a stable zone and

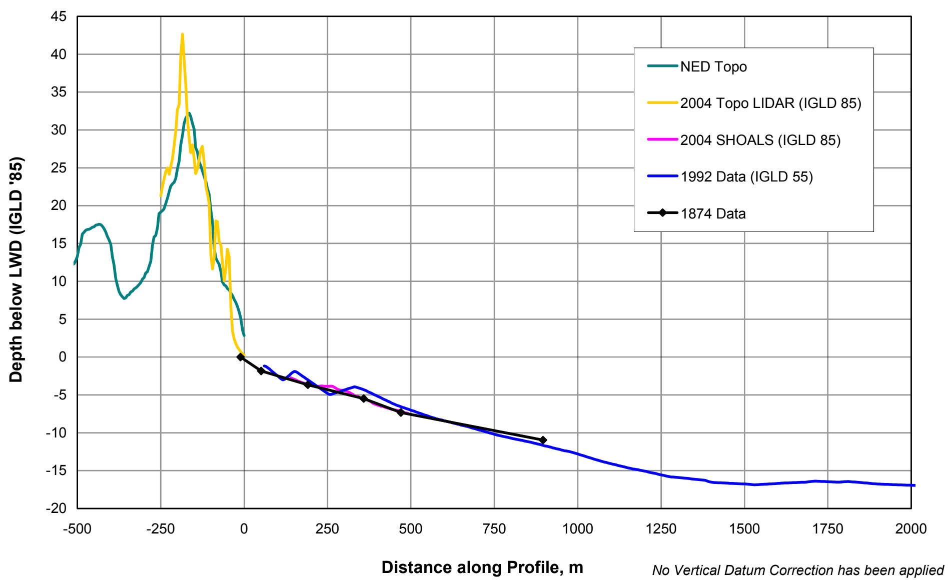


Figure 3.6.3-3 Bathymetry Comparison at Profile I

not impacted by erosion.

3.7 Fillet Beach Volume

The beach profiles outlined in Section 3.6.2 were also utilized to compute the volume of sediment accumulated in the fillet beach following the construction of the first structure for the Michigan City Harbor in 1884. In Figure 3.7-1 the 1874 and 2004 profiles, which are a composite of bathymetric and topographic data, were used to complete area calculations. For example, at Profile B the volume was 10,231 m^2 per meter of shore.

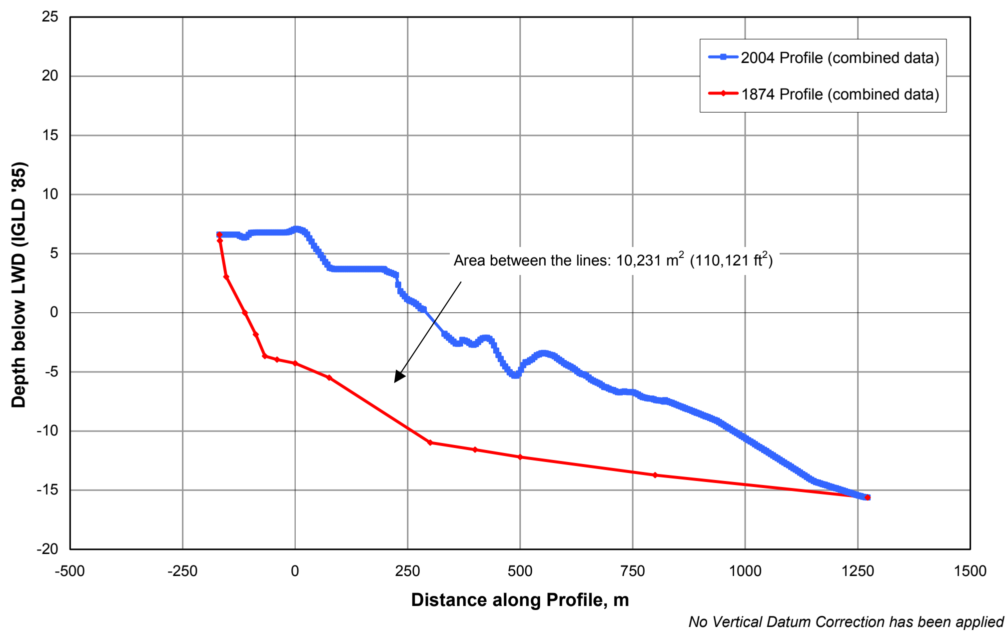


Figure 3.7-1 Fillet Beach Area Calculation for Profile B

This volume per meter is then multiplied by the length of shoreline representative of Profile B to obtain a volume. The procedure is followed for all Profiles, including A to F. The results are summarized in Table 3.7-1 below. The total volume for the fillet beach is 28.2 million cubic meters. Annualized, this volume represents 233,000 m^3 of deposition annually in the fillet beach since 1884.

Table 3.7-1 Updrift Fillet Beach Volume

Profile	Area (m^2)	Distance (m)	Volume (m^3)
A'	5,674	334.6	1,898,500
A	6,686	365.1	2,440,575
B	10,231	604.7	6,186,450
C	5,582	896.1	5,001,617
D	5,650	1,211.1	6,842,146
E	2,770	1,646.9	4,561,643
F	1,368	938.6	1,284,077
Total			**28,215,007**

3.8 Seismic Reflection Data

A sample of the seismic reflection data for the Michigan City Harbor area collected by Ocean Surveys, Inc. is presented below in Figure 3.8-1. Profile 6 is located in the updrift fillet beach, North-East of the Michigan City Marina. The location of the profile corresponds to Profile B generated for this study and presented in Figure 3.6.2-2.

According to the metadata, the seismic reflection in the survey represents shallow discontinuous lithological interfaces below the lake bed. Without borehole data or other

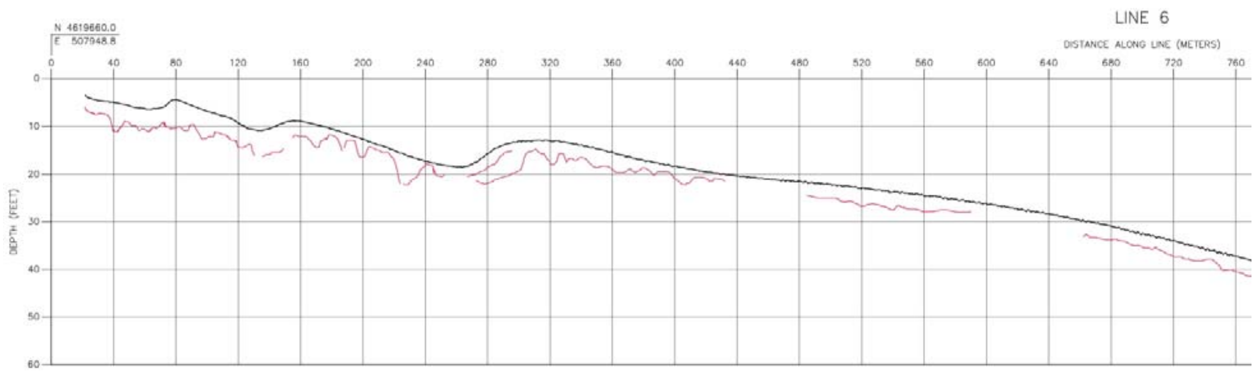


Figure 3.8-1 Seismic Reflection Data for Profile 6, Updrift Fillet Beach

geotechnical data, it wasn't possible to provide a definitive explanation for the occurrence of the reflections.

From the figure above, the interface is on average 5 feet below the modern lake bed. The profile comparisons in Figure 3.6.2-2 (Profile B) indicates the depth of the fillet beach in this location is the order of 10 meters or 33 feet. Therefore, this reflective interface identified in the survey is most certainly not the pre-harbor lake bed. Based on the quantified rate of deposition in the fillet beaches, this reflective surface may be 20 to 30 years old. One potential source for the reflective sand is the coarse nourishment placed downdrift of the New Buffalo Harbor, which began in 1981. In fact, between 1981 and 1985, 340,000 m^3 of coarse sand was trucked to the site from upland sources and placed on the beaches south of New Buffalo. The presence of this sediment may be recorded in the seismic reflection data.

4.0 SEDIMENT MODELING

4.1 Longshore Sediment Transport (LST)

The COSMOS model was applied to calculate the LST rates at 2 km intervals along the shoreline between New Buffalo and Burns Harbor over the 45-year period of 1956 to 2000. A beach profile located at about 5 km east of the Michigan City Harbor was selected as the representative profile for the study area. The profile extended out to a depth of 15 m below the CD and was assumed to be all sandy. It was shown through comparison of historic profiles in Section 3.6 that sand has accumulated to a depth of 15 m in this part of Lake Michigan, and therefore, calculated potential transport rates could be materialized. A uniform sand grain size of 0.3 mm was assumed based on sediment samples collected during the site visit. Waves offshore of the Michigan City Harbor were transformed to 15 m water depth at each calculation point using linear refraction and shoaling equations. The input wave data had a yearly scatter format and was split into North and West wave files (separated at an azimuth of about 335 degrees) to estimate contributions from each direction in addition to the net LST. The contributions will be referred to as southward and northward components, respectively, hereafter. Calculations were conducted at 20 different points along the shoreline.

Figure 4.1-1 shows the variation in net LST rate as well as its northward and southward components at a point 5 km north of Michigan City over 45 years. More variations are observed in the magnitude of the southward component of LST than the northward

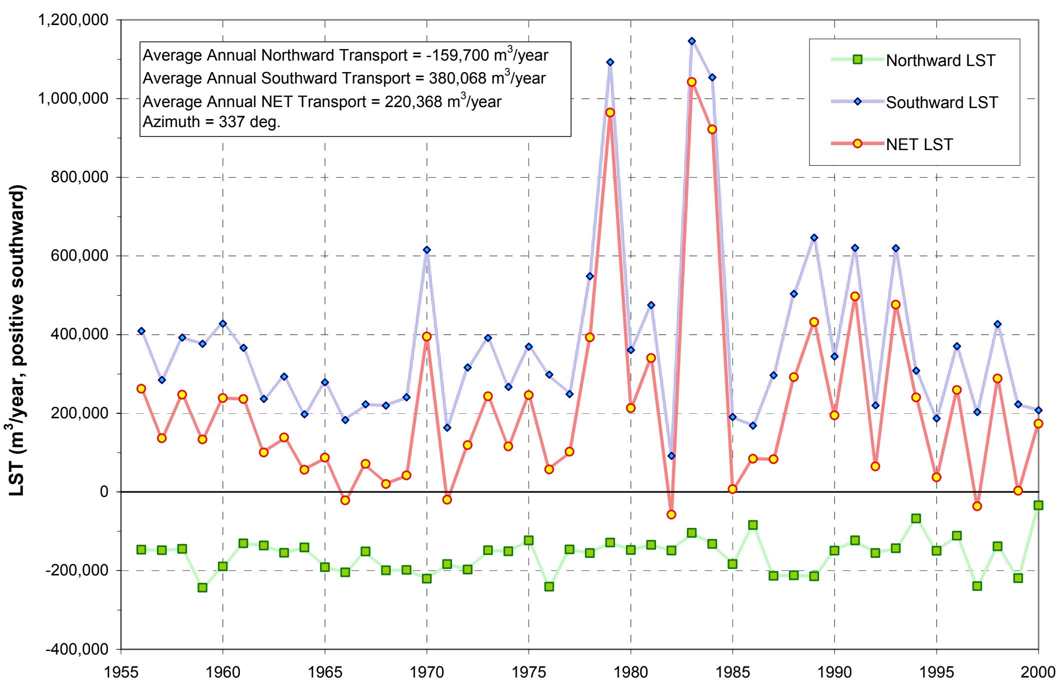


Figure 4.1-1 45-year Variation in LST 5km North of Michigan City Harbor

component, which varies within a limited range. Although a net southward transport is predominant, a considerable variation in net LST is observed every few (3 to 5) years. The net LST was relatively small from 1962 to 1969, close to zero in 1971, 1982, 1985, 1997 and 1999, and reached a maximum of nearly 600,000 m^3/year in 1983, indicating a multi-decadal periodicity as well. These features can be accounted for by considering the periodicities of the synoptic scale and meso scale weather systems that affect the Great Lakes in general, and Lake Michigan in particular. In terms of 45-year average values, it may be seen that average southward LST is 380,000 m^3/year, while average northward transport is 160,000 m^3/year. The averaged net annual LST at this location is 220,000 m^3/year for the selected 45-year time period.

Figure 4.1-2 shows the 45-year average annual cross-shore distribution of LST at this location. Sediment motion extends out to beyond 10 m below CD. The existence of two bars on the profile results in two peaks in the LST curves. The shallow depths over the bar result in larger depth average current and near-bottom orbital velocities, leading to higher LST rates. A larger near-bottom orbital velocity results in more intensive stirring of sediment and a larger current velocity can simply transport all that sediment. There is also a third peak near the shoreline in the swash zone followed by a change in net transport direction from south to north. The northward transport is a result of the cumulative effect of smaller waves. These waves arrive mostly from west as a result of smaller fetch in the west direction compared to the north fetch. Regional variations of LST are discussed in the following subsections.

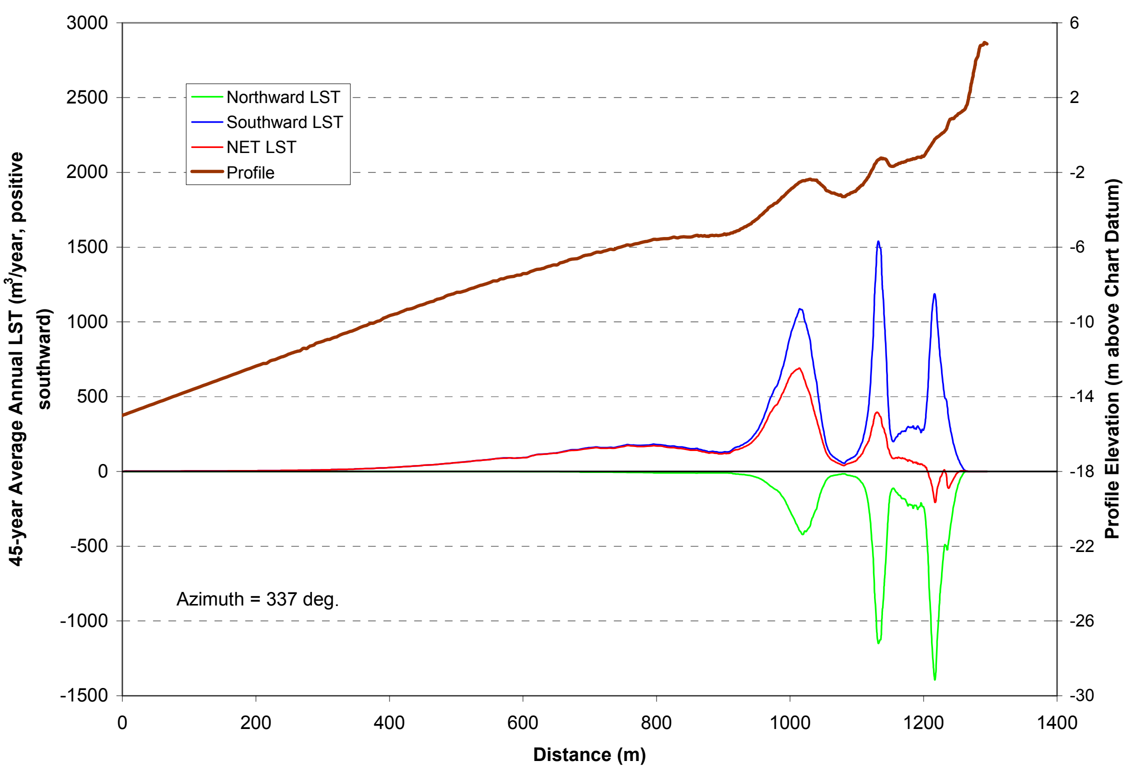


Figure 4.1-2 Cross-shore Distribution of LST 5 km North of Michigan City Harbor

4.1.1 LST for Pre-Harbor Shoreline

In order to understand the regional LST pattern prior to construction of the harbors COSMOS runs were repeated for the shoreline and the shoreline orientation based on the 15 m contour taken from the 1874 historical survey. Calculated pre-harbor regional LST and its northward and southward components are shown in Figure 4.1.1-1. In this figure, distances are referenced to Michigan City Harbor which is located at 0 km. It may be seen that net LST decreases gradually from 250,000 m^3/year at New Buffalo to about 170,000 m^3/year at Burns Harbor. A test run at 10 km west of Burns harbor resulted in a small net Eastward transport indicating that Burns Harbor is a convergent node for LST. The calculated negative LST gradient (decreasing LST towards the downdrift) is an indication of a long term accretion trend for the regional shoreline in the study area. Historically, therefore, the shorelines between New Buffalo and Burns Harbor were accreting. This trend is also in agreement with the results of profile comparisons downdrift of New Buffalo (Section 3.6), which showed that the beach was advancing until the late 1900s. This long term trend of accretion also supports the lake level studies of Baedke and Thompson (2000), which document the formation of the Indiana Dunes at the southern end of Lake Michigan over the last 4,700 years.

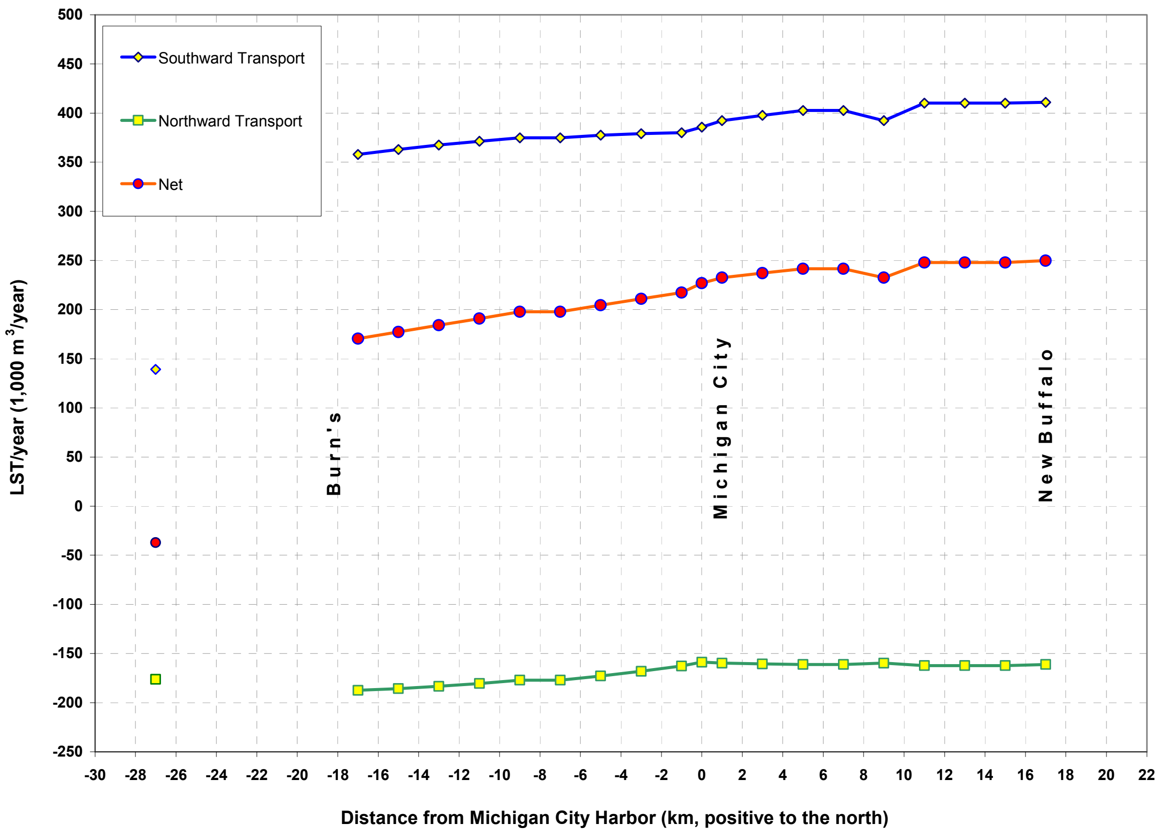


Figure 4.1.1-1 Historic Regional LST Distribution (0.3 mm)

The pre-harbor net LST rate calculated at Michigan City is about 230,000 m^3/year. Fillet beach volume calculations in Section 3.7 indicated an average accumulation volume of about 220,000 m^3/year over past 130 years. Considering the harbor structures have been a significant barrier to sediment bypassing, especially from the late 1800's to mid 1900's, they would have trapped a significant percentage of the southward LST. Therefore, there is good agreement between the historical net LST rate prior to the harbor construction and the infilling rate for the updrift fillet beach. This comparison provides confidence in the COSMOS estimates which are used to formulate the sediment budget.

4.1.2 LST for Existing Conditions

Calculated regional LST rates for the existing conditions between New Buffalo and Burns harbors are shown in Figure 4.1.2-1. The calculated historic rates from the previous section are also shown in this figure for comparison. While the potential incoming and outgoing transport rates to the study area are the same as their historic rates, differences are noticed around the Michigan City Harbor. It may be seen that the formation of the updrift fillet and the resulting change in the shoreline orientation has resulted in a stronger negative LST gradient than the pre-harbor condition. This fact combined with the trapping potential of the harbor are the principal factors responsible for the creation and growth of the fillet beach. Immediately downdrift of Michigan City Harbor, a positive or increasing LST gradient extending to about 6 km downdrift is calculated, which is believed to be responsible for the observed erosion in that area. These findings will be discussed further with the *HYDROSED* modeling results.

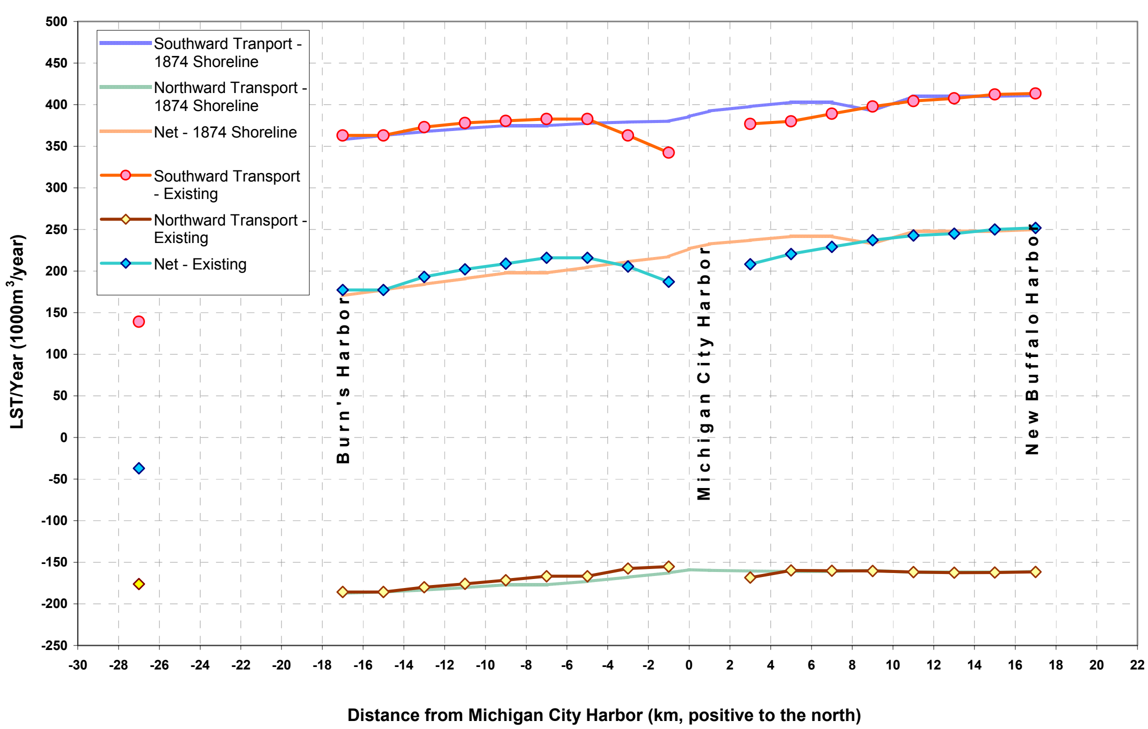


Figure 4.1.2-1 Existing Regional LST Distribution (0.3 mm)

4.2 *HydroSed* Modeling

In order to improve our understanding of the hydrodynamics at the harbor, patterns of sediment transport around the piers and the role of Michigan City Harbor in the regional sediment budget, a hydrodynamic and sediment transport analysis was completed. The analysis is conducted based on calculated wave field and depth averaged flows in two horizontal dimensions. The driving forces considered behind the movement of sediments are the wave-induced orbital motion, the nearshore current system including longshore and circulation currents, and the undertow.

A 2DH hydrodynamic and sediment transport model (*HydroSed*) was applied to the analysis of the existing conditions of waves, nearshore currents and sediment transport at Michigan City. This is a state of the art model that consists of a spectral wave transformation model, where the wave field is calculated by the spectral energy conservation equation of Karlsson (1969), with the breaking dissipation term of Isobe, (1987), a hydrodynamic model (Nishimura, 1988) to describe wave generated nearshore currents and circulations (driven by radiation stresses predicted with the spectral wave transformation model) and a sediment transport model presented by Dibajnia et al (2001). The sediment transport model considers the influence of non-linear orbital velocities and undertow and is based on the sheet flow transport formula of Dibajnia and Watanabe (1992), which was extended by Dibajnia (1995) to consider suspended transport over ripples as well as the bedload transport. Dibajnia et al (2001) also conducted a sensitivity test of their model and showed that the model response under various actual nearshore wave environments is satisfactory. For a given wave condition, *HydroSed* can provide a full spatial description of nearshore currents and sand transport around the harbor. The model has been verified through laboratory experiments as well as field measurements and has been extensively applied to projects by Baird in the past several years.

A 300 × 650 mesh (cross-shore × alongshore) with grid size of 10 m (resulting in a calculation area of 3 ×6.5 km) was selected for the model. Figure 4.2-1 shows the calculation domain and its bathymetry. The bathymetry was constructed using a combination of 2004 SHOALS data, a 2003 channel survey and the 1992 NOAA lake-wide bathymetry. The depth at the offshore boundary of the calculation domain was 18 to 19 m. The calculation domain was selected to ensure that most of the updrift accretion fillet and downdrift erosion zone of the harbor was covered. A median grain size of 0.3 mm was used for the sediment. Bretschneider-Mitsuyasu type directional spectrum with directional spreading factor, $\boldsymbol{S}_{\max}$, of 35 (i.e. swell with short decay distance and relatively large wave steepness, see Goda 1985) was used for the waves.

4.2.1 *Example Calculations*

An incident storm wave height of 3 m, wave period of 9 second and wave direction of 0.0 degrees corresponding to North waves was selected as the first example. Figure 4.2.1-1 shows the calculated wave height and directions for this wave condition. It may be seen that the breaking zone is aligned with the tip of the east jetty. Large waves penetrate through the entrance of the harbor but dissipate/diffuse rapidly. Figure 4.2.1-2 shows

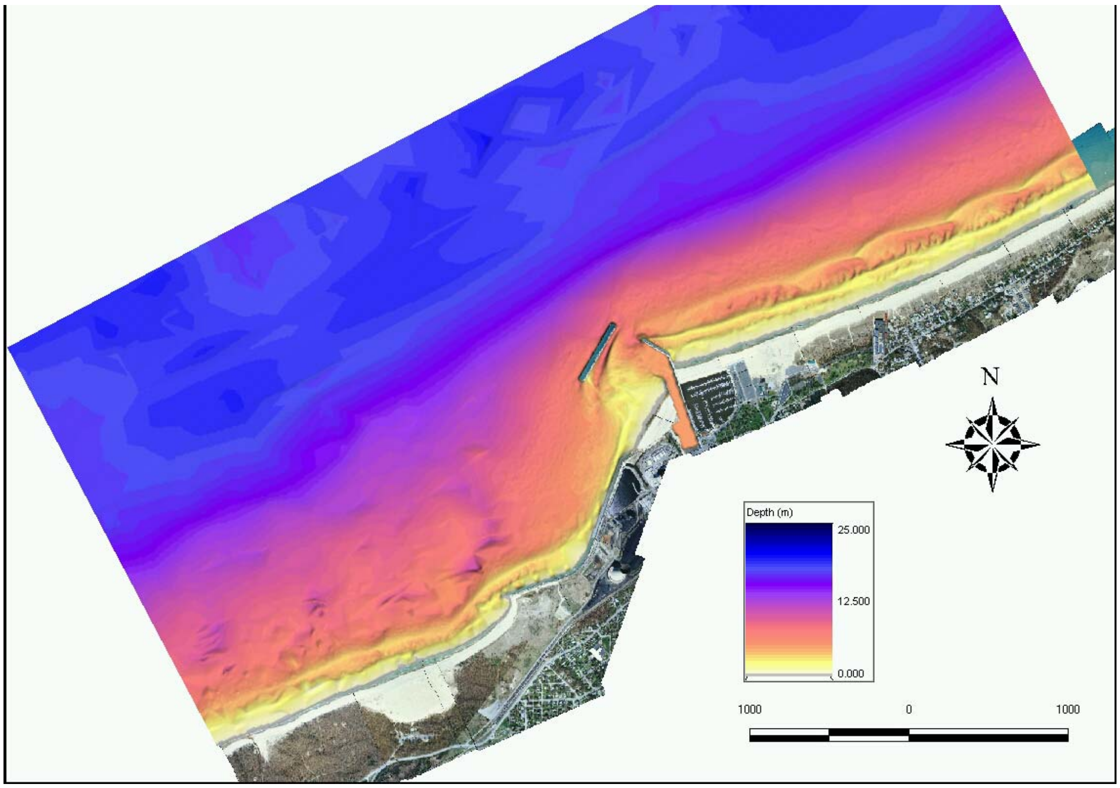


Figure 4.2-1 Calculation Domain and Bathymetry for HYDROSED Model

calculated nearshore current velocity vectors. The westward longshore current divides at the harbor into two steams. One of the streams flows through the harbor entrance along the detached offshore breakwater into the downdrift area. This current is responsible for part of the sedimentation in the navigation channel. The second stream follows an outer path offshore of the detached breakwater, but can hardly make it into the downdrift area because of the large depths on its way. There is little wave activity and thus little sediment entrainment in the area sheltered by the detached breakwater and therefore, although longshore current seems to reach downdrift through the above-mentioned first stream, it is likely not able to carry much sediment. No particular circulation current is observed downdrift of the harbor.

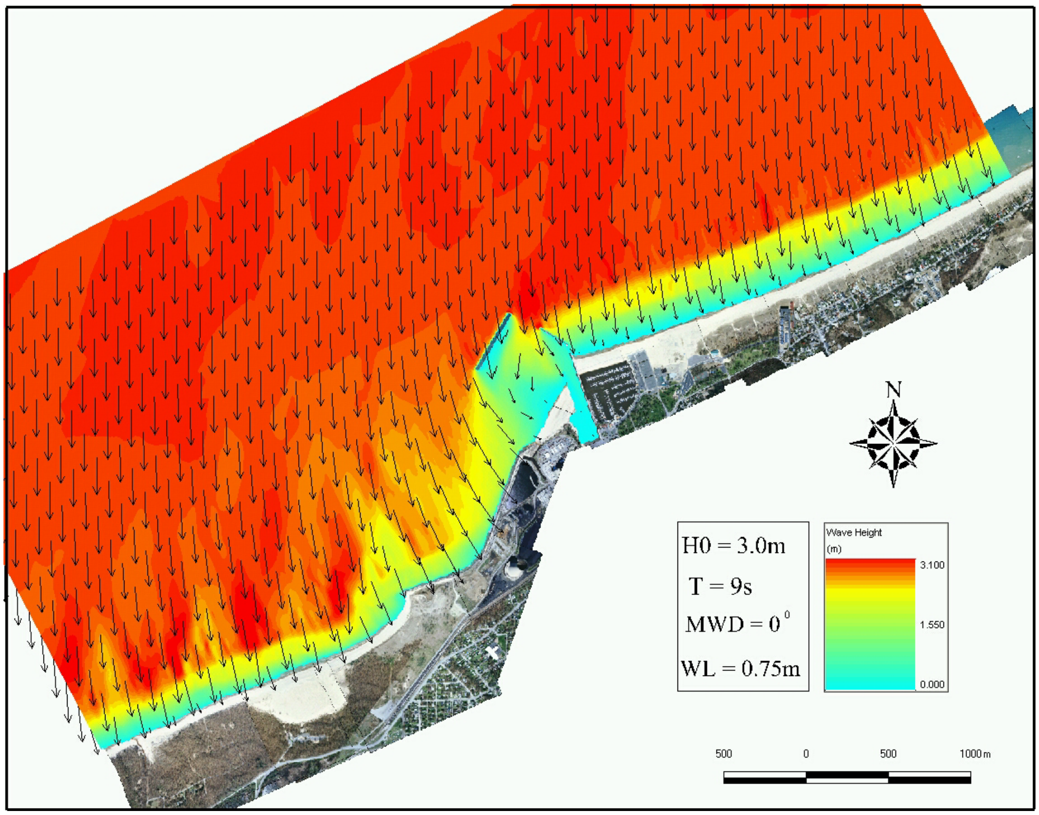


Figure 4.2.1-1 Wave Height and Direction Vectors for a 3.0 m, 9 second Wave

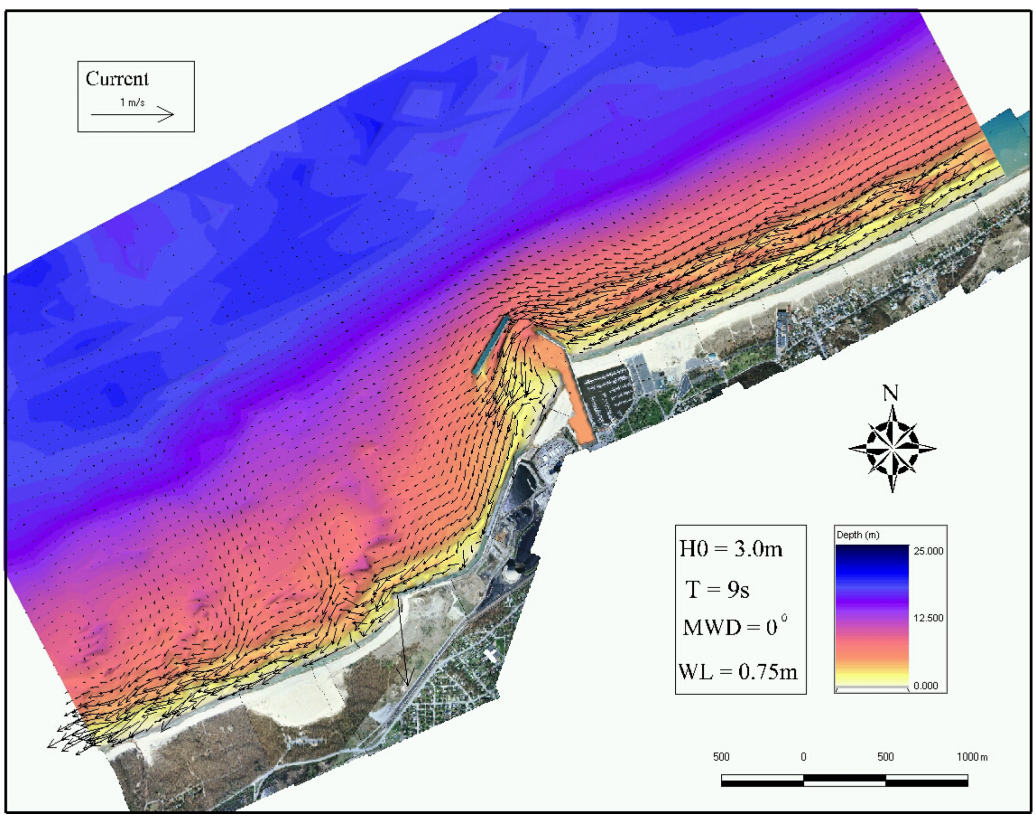


Figure 4.2.1-2 Calculated Nearshore Current Velocity Vectors

Figure 4.2.1-3 shows the resulting sediment transport vectors. Convergence of transport rate vectors indicating the formation of a bar is observed over the accretion fillet. Transport rate vectors through the harbor entrance cause sediment infilling into the navigation channel. There is no considerable sediment transport from the west jetty into the downdrift area. For the present wave condition, *HYDROSED* prediction amounts to 60 m^3/hr infilling through the harbor entrance, 22 m^3/hr outgoing through the west gap and 26 m^3/hr bypassing around the lake side of the offshore breakwater (mostly due to nonlinear oblique waves). In the downdrift vicinity of the harbor, contrary to the accretion fillet area, transport vectors are more offshore directed and onshore transport by nonlinear waves is not observed due to large depth and steep beach slope.

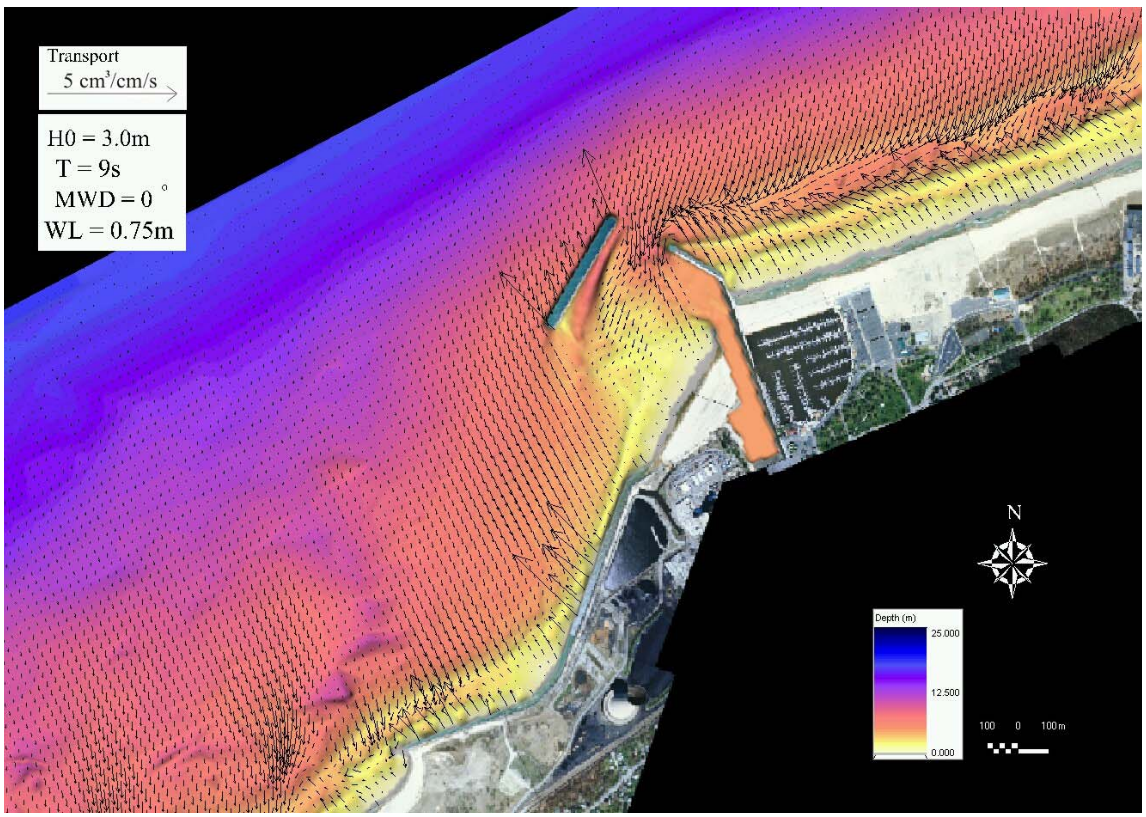


Figure 4.2.1-3 Calculated Sediment Transport Vectors

The longshore component of transport was integrated over the cross-shore at each point along the shore and the results are summarized in Figure 4.2.1-4 for the present wave condition (red line) and four other wave conditions with different incident wave heights. It was assumed the beach was covered with sand out to 15 m below CD in the cross-shore integrations. The longshore transport direction is from North-east to South-west. The 2002 air photo was added to the graph to help understand the alongshore location. LST values at the location of the offshore breakwater indicate the amount of bypassing for each wave condition. For the present example wave condition it may be seen that only about 25% of the updrift LST gets bypassed through the lake side path of the offshore breakwater). For the extreme storm of 6 m height and 11 s period, bypassing is nearly 100% and for smaller waves of 1.5 m height and 0.5 m there is almost no bypassing.

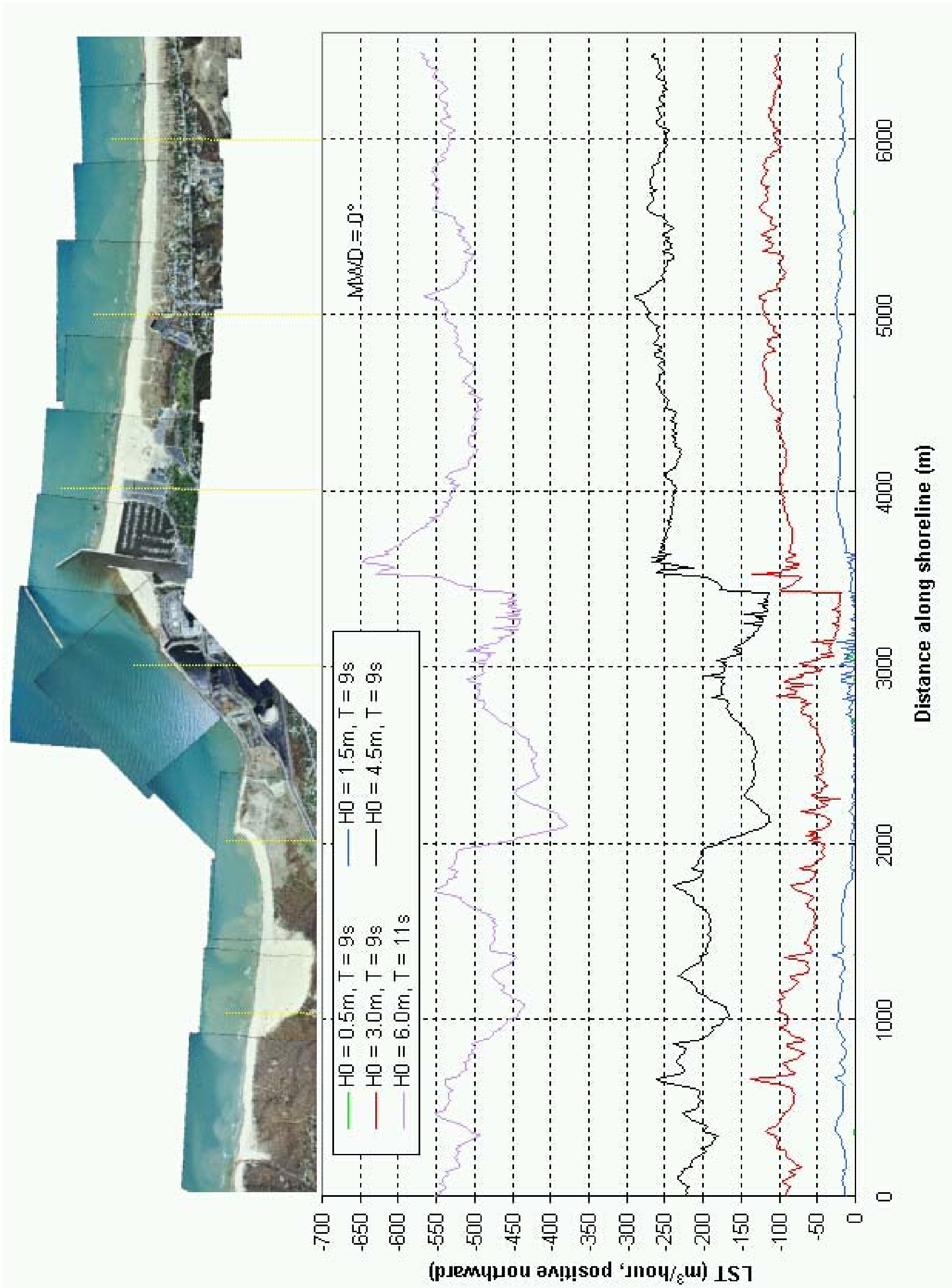


Figure 4.2.1-4 Longshore Sediment Transport for Four Wave Conditions

The second example is for a WNW storm wave event with an incident wave height of 3 m, wave period of 7 s and wave direction of 293 degrees. The shorter wave period than the one of the first example is because west fetch has a shorter length than the north fetch. Figure 4.2.1-5 shows the calculated wave height and directions for this wave condition. It may be seen that the breaking zone is aligned with the tip of the east jetty. The harbor and its navigation channel are well protected against this wave condition. A close up of the harbor area is shown in Figure 4.2.1-6. It may be seen that although the

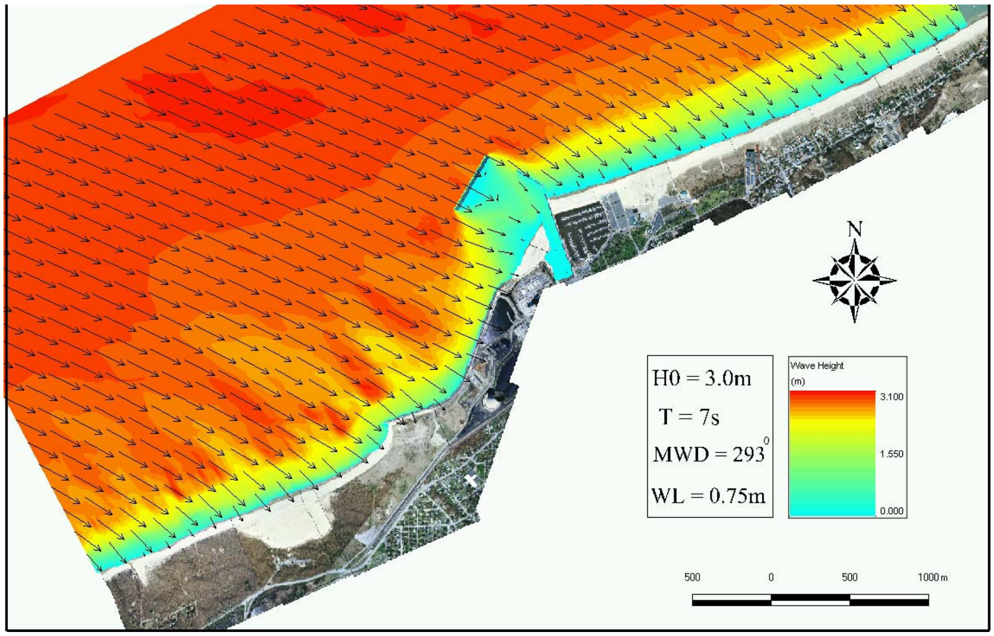


Figure 4.2.1-5 Wave Height and Direction for a WNW Storm

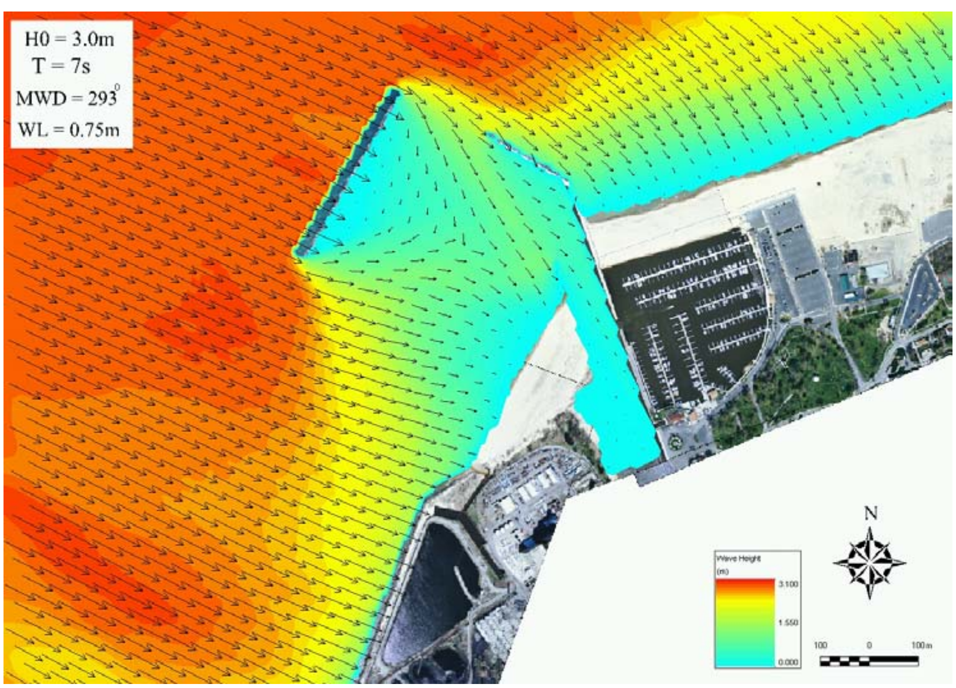


Figure 4.2.1-6 Zoom of Harbor for a WNW Storm

spectral wave module of *HYDROSED* does not include explicit diffraction calculations, the model has calculated a virtual but reasonable diffraction pattern behind the offshore breakwater as a result of multi-directional calculations. Figure 4.2.1-7 shows a close up of calculated nearshore current velocity vectors around the harbor. The North-east longshore current downdrift of the harbor slows down offshore of the NIPSCO plant and is only a minor contribution to the circulation current that is formed behind the offshore breakwater. There is no evidence of a continuous strong bypassing current from the

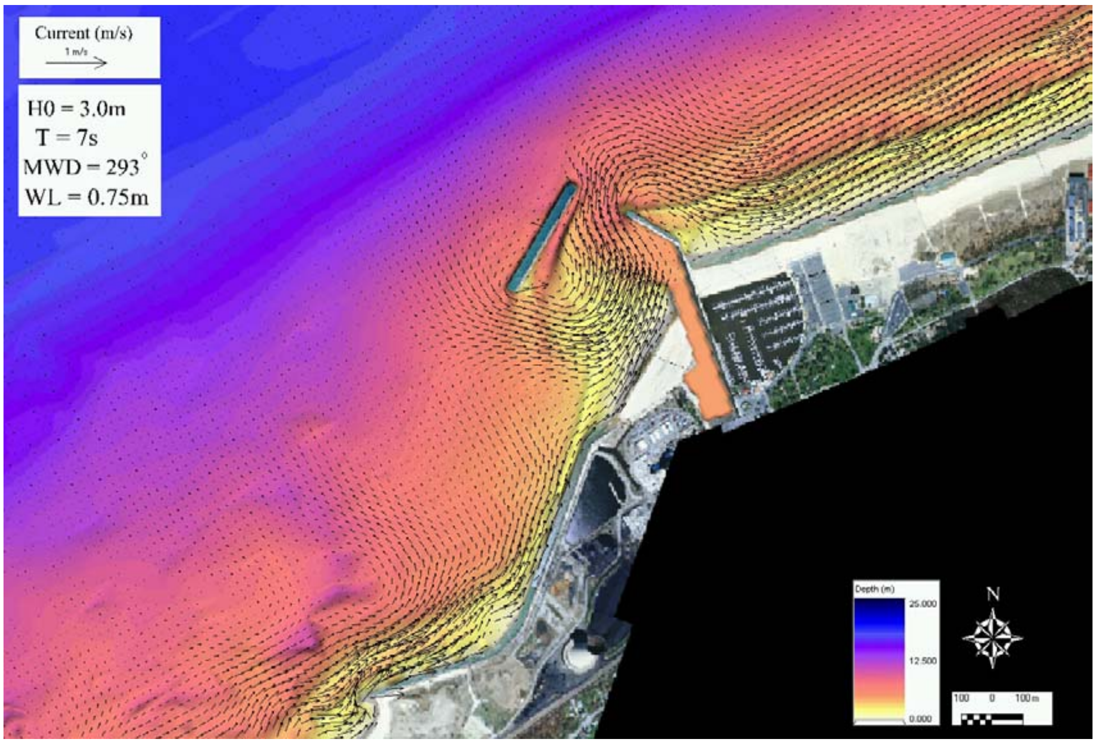


Figure 4.2.1-7 Current Predictions at the Harbor

South-west.

Examination of calculated sediment transport rate vectors for this wave condition indicated a prediction of 12 m^3/hr infilling through the west gap, almost zero outgoing through the gap at the harbor entrance and almost zero bypassing around the lake side of the offshore breakwater. The calculated alongshore LST distributions for the present wave condition (red line) and similar incident waves with different wave heights are shown in Figure 4.2.1-8 with the 2002 air photo superimposed. The predominant longshore transport direction is from west to east (positive values). For all the storms, however, it may be seen that LST offshore of NIPSCO is almost zero. This is due to the NNE-WSW orientation of the shoreline at this location that results in nearly zero transport for almost all wave conditions. One important implication of the present results is that there is likely no bypassing of sediment from west to east of the harbor.

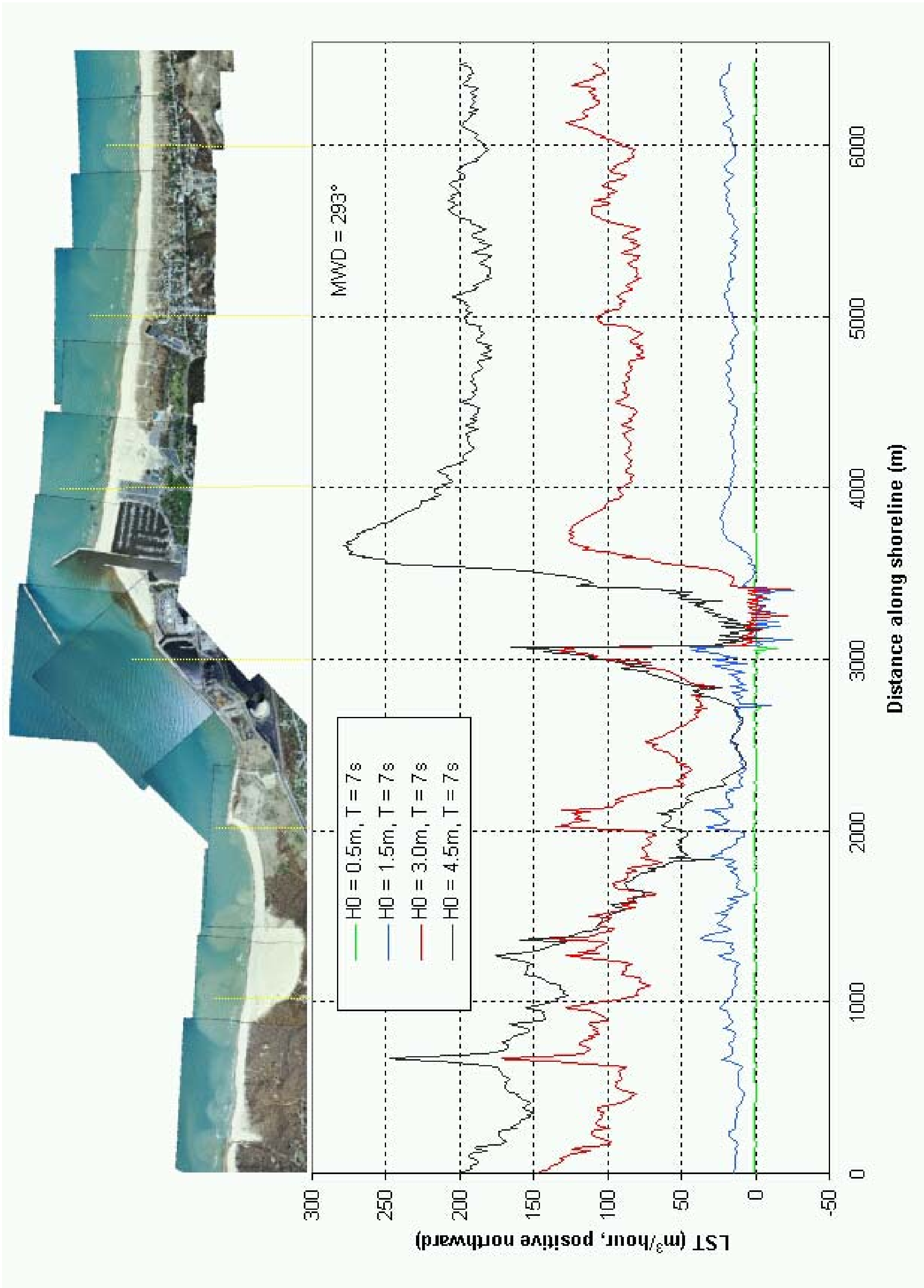


Figure 4.2.1-8   LST Estimates for WNW Waves

Finally, in order to demonstrate the accuracy of HydroSed spectral wave module in the harbor area, the calculated wave directions were superimposed on a 2002 air photo of the Michigan City Harbor. Looking at wave crests, their spacing and location of the breaking waves, the wave conditions at the time of photography were estimated to be 1.0 to 1.5 m wave height, 5 s period and NNW (338 deg) direction. Figure 4.2.1-9 shows the results. It may be seen that *HYDROSED* has done a satisfactory prediction.

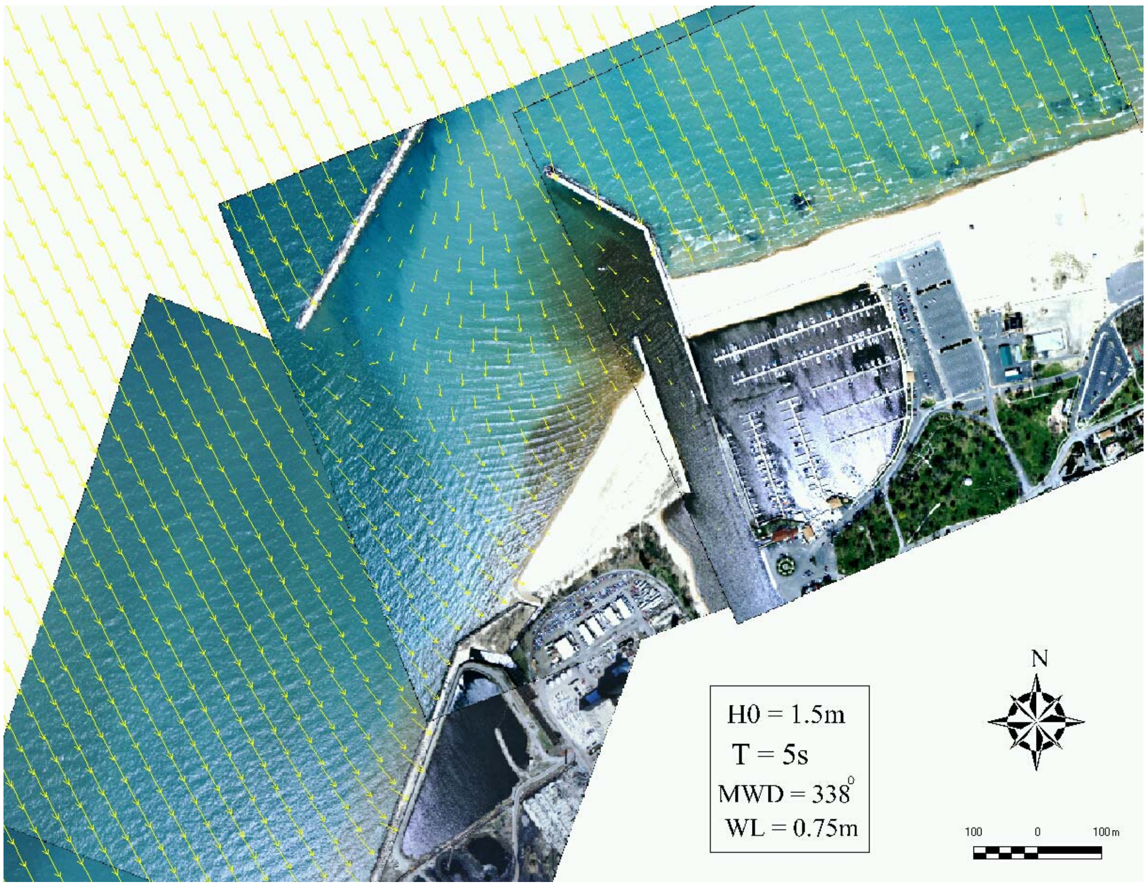


Figure 4.2.1-9 Comparison of HYDROSED Results with Conditions in Aerial Photo

4.2.2 Long-term Modeling

Although the *HYDROSED* model can provide valuable insight into the sediment dynamics and bypassing process, it is computationally time consuming and, at present, it cannot be applied to an hourly time series of wave conditions spanning over more than several days. A hybrid approach was therefore applied as follows. *HYDROSED* was run for a collection of representative wave, water level and river flow conditions and the results were formulated as functions of the relevant hydraulic parameters. The approach consisted of developing a simple numerical model that used the resulting formulations and stepped through a time series of hourly wave data to determine the long-term sediment transport quantities. The formulations, however, are site-specific as they are obtained for the special arrangement of structures and bathymetry at Michigan City.

A series of calculations were conducted to determine the overall trends of channel infilling and bypassing and their variation with changing incident wave conditions, water levels and river flow discharge. The applied wave conditions were selected based on a statistical analysis of the 45-year wave hindcast and cover five different wave heights, 5 wave periods, and six wave directions (see Table 4.1).

Table 4-1: Matrix of Wave Periods (Tp) by Height and Direction [a]

Wave Direction [b]		Significant wave height (m)				
Direction	Central Azimuth	0.5	1.5	3	4.5	6
W	270º	3,5,7	5,7	5,7	7	
WNW	292.5º	3,5,7	5,7	5,7	7	
NW	315º	3,5,7	5,7	5,7	7	
NNW	337.5º	3,5,7,9	5,7,9	5,7,9	7,9	
N	360º	3,5,7,9	5,7,9	5,7,9,11	7,9,11	11
NNE	22.5º	3,5,7,9	5,7,9	5,7,9	7,9	

[a] Wave Period in seconds.
[b] Direction from.

Three water levels of –0.25 m, +0.75 m and +1.5 m above Chart Datum were chosen as representatives of historic low, average and high water levels, respectively. Calculations were conducted for two river flow discharges of 0 and 6 m^3/s for the calculation grid, but only for the +0.75 m water level. The nonzero river flow corresponds to an annual flood event of 30 m^3/s and was found to have insignificant effect on the results. The river flow discharge was thus discarded in the long-term analysis. The sand grain size was 0.3 mm. In total, 252 cases were calculated requiring about 500 hours of calculation time.

In order to classify the results, the Kamphuis (1991) approach for estimation of longshore sand transport rate was used and the following parameter was employed to represent the above environmental conditions:

$$\Theta = H^2 T^{1.5} \sin^{0.6} 2\alpha$$

where H, T and α are the incident wave height, wave period and wave angle at the offshore boundary of the calculation domain, respectively. It should be mentioned that the original formulation of Kamphuis includes the bottom slope and the sediment grain size, which are omitted here because they are the same for all the cases. Also in the original formulation, the above values are to be specified at the breaking point.

However, the values at the offshore boundary of the calculation domain were applied because the parameter was used only for classification of the results.

Figure 4.2.2-1 shows the relation between calculated LST rates (average incoming LST across the first 800 m from the side boundary on the East of the calculation domain) and the parameter Θ. Negative values for Θ correspond to N waves. A well-defined trend is observed that can be formulated as indicated in the figure. Best results were obtained when 5 degrees was added to the incident wave angle to incorporate the local shoreline orientation more accurately. It should be mentioned that the LST rates are the output from the *HYDROSED* model without any calibration and therefore do not necessarily match actual values. This is, however, of minor concern because the main interest is in ratios of bypassing and infilling rates rather than their actual quantities. Actual LST values will be deduced from the calculated fillet volumes and COSMOS simulation results.

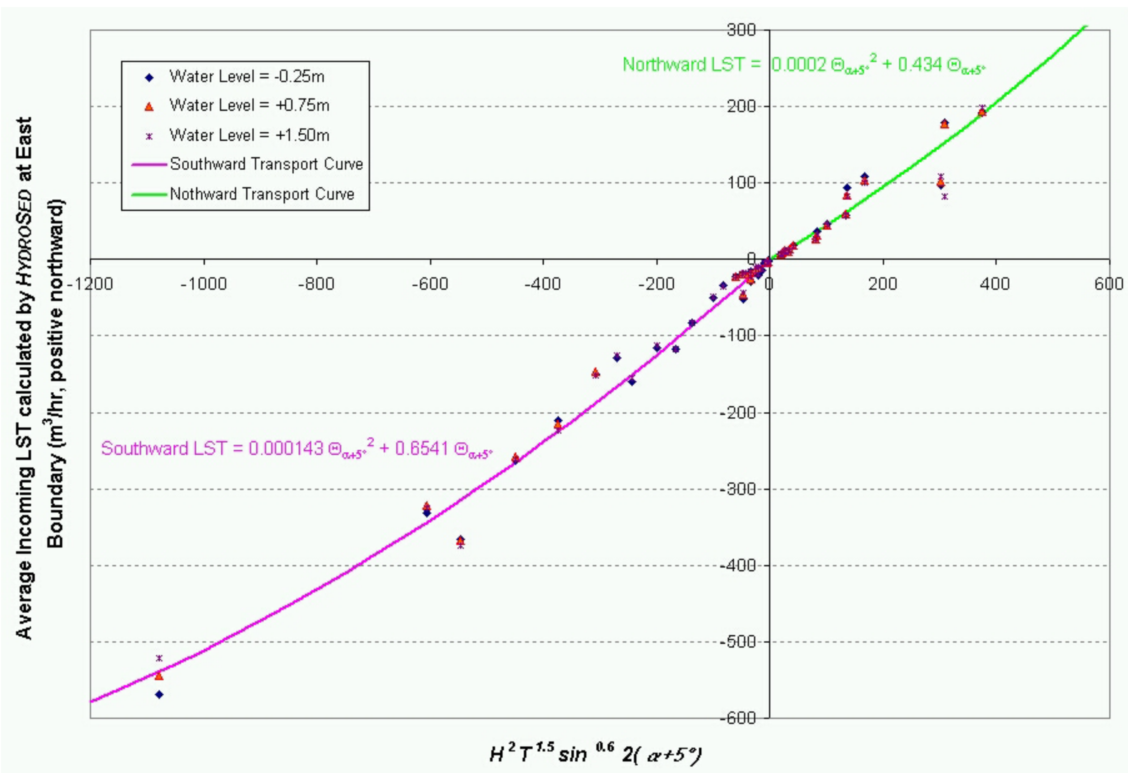


Figure 4.2.2-1 Relationship Between LST and Parameter Θ

Figure 4.2.2-2 is a plot of the calculated bypassing rates for all 252 simulations. Bypassing rate was defined as average LST rate lakeward of the offshore breakwater. Sediment transport through the east and west gaps between the offshore breakwater and the jetties/shoreline was considered infilling, not outgoing transport, and was not included in bypassing rate. From this figure it may be seen that bypassing rate varies with the water level and is larger for a lower water level. For the water level of +0.75 m the results with nonzero river flow are also shown and indicate that bypassing rate is independent of river flow discharge. Figure 4.2.2-2 indicates that bypassing rate is generally very small for positive values of the parameter Θ. In other words, bypassing from west to east of the harbor during W storm events is close to zero. It is only during extreme storm events combined with historic low lake levels that some west to east bypassing may happen. The solid lines in this figure indicate the formulations established for this study.

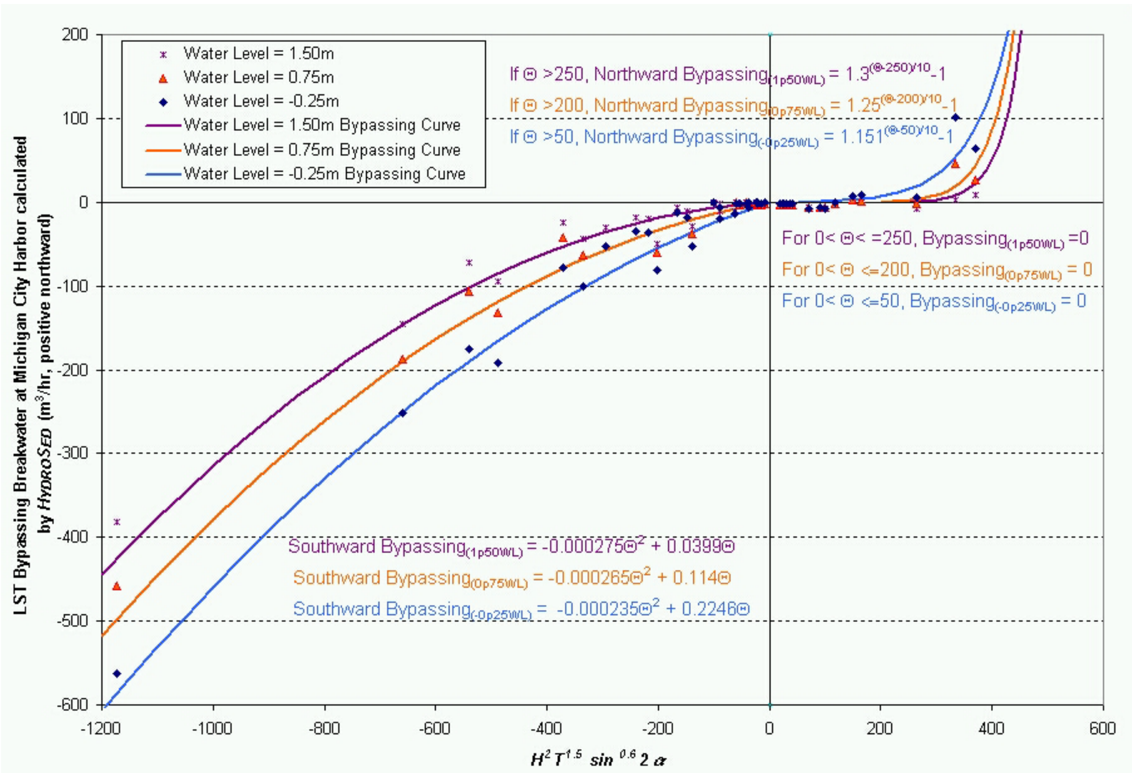


Figure 4.2.2-2 Bypassing Rate versus Parameter Θ

Figure 4.2.2-3 shows the calculated sediment infilling (positive) or outgoing (negative) through the East gap (between the offshore breakwater and the East pier) for all the simulations. Outgoing sediment transport is predicted during West wave events (positive Θ). However, the curve in the figure suggests transport is small except for the very large wave conditions from the West. Sediment infilling rate, on the other hand, mostly happens during North waves, depend on the lake level, and on the relative location of the gap and the surf zone of the corresponding wave condition. The infilling rates corresponding to the three water level cases (-0.25, +0.75 and +1.5 m) are formulated as a function of Θ as shown in Figure 4.2.2-3. For all three water levels, it may be seen that the infilling rate increases with an increase in wave height until it reaches a maximum beyond which any further increase in wave height results in less infilling.

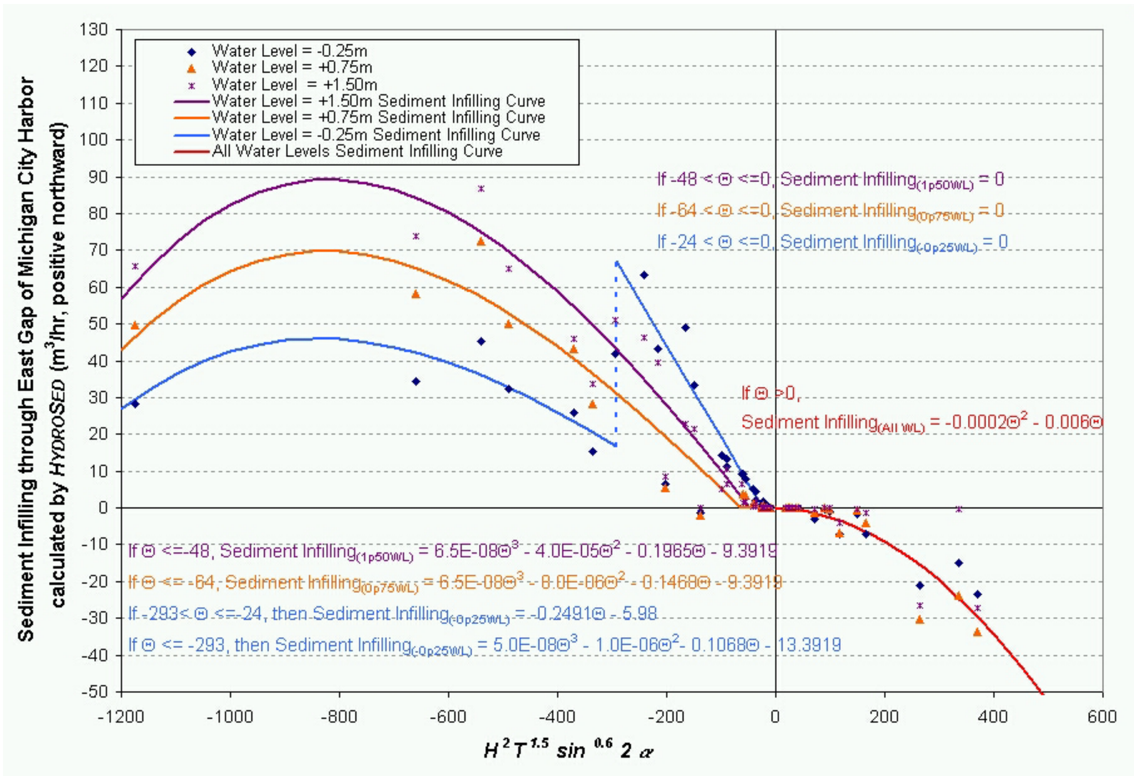


Figure 4.2.2-3 Eastern Gap Sediment Infilling Curve for 1.5 m WL versus Parameter Θ

This behavior corresponds to the change of the surf zone width and the location of the breaker zone with the incident wave height. Maximum infilling is likely to occur when the gap is right in the breaking zone of the waves and minimum infilling happens when the gap is well outside of the surf zone and waves break close to the shoreline. Other sediment transport quantities were also formulated as functions of Θ or similar parameters and are given in Appendix B at the end of this report. The formulations will be used in the next section for the assessment of the current conditions and development a sediment budget at Michigan City.

4.3 Sediment Budget

A sediment budget assessment attempts to reconcile all sinks, sources, inputs, and outputs of sediment within a confined cell or boundary. This approach provides the framework to describe and understand morphological changes, such as erosion and sedimentation rates. This section describes the development of a sediment budget for the current situation at Michigan City based on our findings from the numerical modeling and geomorphologic analysis. It is this analysis that ultimately allows for an assessment of future dredge management scenarios and their corresponding consequences on the harbor and adjacent shorelines (i.e. erosion and sedimentation rates).

The bypassing, infilling and LST rate formulations obtained in the previous section were applied to the 45-year wave hindcast data in a time series analysis to obtain the overall sediment transport quantities for the current shoreline configuration and bathymetry. It was discussed in Section 4.1 of this report that the LST at Michigan City has northward and southward components (strictly speaking, northeastward and southwestward, respectively). The 45-year wave data was thus split in North and West wave files to estimate the long-term quantities corresponding to waves from the two directions. The monthly mean water level data were used and the river flow was discarded as it had negligible effect on *HYDROSED* results. The wave files consisted of successive hourly wave and (monthly) water level data. The time series during ice cover periods were excluded.

The 45-year average LST results by the present hybrid approach were used to construct a sediment budget for the current situation at Michigan City Harbor. The South-west LST rate is 377,000 m^3/year at the North-east limit of the updrift fillet beach. The North-east component at this location is 157 m^3/year, giving a net LST rate of 220,000 m^3/year. This net LST rate compares well with the long term sedimentation rate for the fillet beach based on the volume comparisons in Section 3.7. The South-westward LST decreases as it approaches the harbor, first to 200,000 m^3/year, then 137,000 m^3/year at the East pier. As the LST gradient decreases, a total of 157 m^3/year of sediment is deposited in temporary sinks on the lake bottom.

Since there is no significant bypassing to the North-east during storms from the West, sediment from the Burns Harbor to Michigan City sub-littoral cell never reaches the Michigan City to New Buffalo sub-littoral cell. Therefore, the North-east LST rate at the harbor is essentially zero. However this rate quickly increases to 63,000 m^3/year and then 157,000 m^3/year further from the harbor. Lake bed erosion from the temporary sediment sinks above are the main source of material transported to the North-east. There is an additional permanent sediment sink of 83,000 m^3/year for the updrift fillet beach, suggesting that the deposit will continue to grow above and below the water in the future.

The net LST rate at the gap between the East pier and offshore breakwater is 31,000 m^3/year. Since the Southward directed currents are not sustained between the West fillet and offshore breakwater, deposition occurs on the lake bottom. During West storms, currents transport this sediment into the navigation channel and the West fillet beach. These sedimentation rates compare well to the historical dredging records and the volume of sediment accumulated in the West fillet beach.

Offshore of the breakwater, an additional 106,000 m^3/year of sediment is transported in a South-west direction across the bypassing shoal. The potential transport rate decreases to 76,000 m^3/year South of the offshore breakwater, resulting in the deposition of 30,000 m^3/year of additional sediment to the bypassing shoal. The 76,000 m^3/year continues past the NIPSCO seawall towards Mount Baldy. Closer to shore, sediment is moved in small quantities back and forth along the seawall, as indicated on Figure 4.3-1, but there is no net LST rate.

The long term LST rate from Beverly Shores towards the National Lakeshore and Mount Baldy is 92,000 m^3/year. Because of the offset in the shoreline at the Crescent Dune and the deep depths offshore of the NIPSCO seawall, none of this sediment reaches the harbor. Rather, it is stored in a temporary sediment sink on the lake bottom and along the shore. Refer to Figure 4.3-1. During storms from the North, the LST rate quickly increases to 281,000 m^3/year in front of Mount Baldy and the National Lakeshore. In addition to the 76,000 m^3/year of sediment from natural bypassing, there are four other sand sources: 1) 15,000 m^3/year dredged from the navigation channel and mechanically bypassed, 2) 17,000 m^3/year trucked to the site from upland sources, 3) 81,000 m^3/year from shoreline and dune erosion, and 4) 92,000 m^3/year of sediment from the temporary sink associated with North-east sediment transport. Collectively, these four sources added to the sediment from bypassing equal the 281,000 m^3/year transported to the South-west.

In summary, the results of the sediment budget for the existing conditions is summarized in Figure 4.3-1. The following findings are significant for the development of a DMMP:

- The updrift fillet beach is expected to increase in size, although at a reduced rate to the historical infilling volumes. The 83,000 m^3/year is now spread over a very long reach of shore (~3 km) and deposited along the shoreline to depths of 15 m below LWD. Additional sand is transported inland by aeolian processes and deposited in the dunes,

- Sediment that enters the gap between the East pier and offshore breakwater does not bypass the harbor and results in either channel sedimentation or accumulation in the West fillet beach. This process is expected to continue indefinitely,

- There is some natural bypassing of the offshore breakwater (76,000 m^3/year), although this volume is small compared to the net LST rate that reaches the harbor, and

- There is a deficit of approximately 80,000 m^3/year for the downdrift shoreline at Mount Baldy. The sediment dredged from the navigation channel and mechanically bypassed, plus the trucking from upland sources contribute to the deficit and without this sand downdrift erosion would increase.

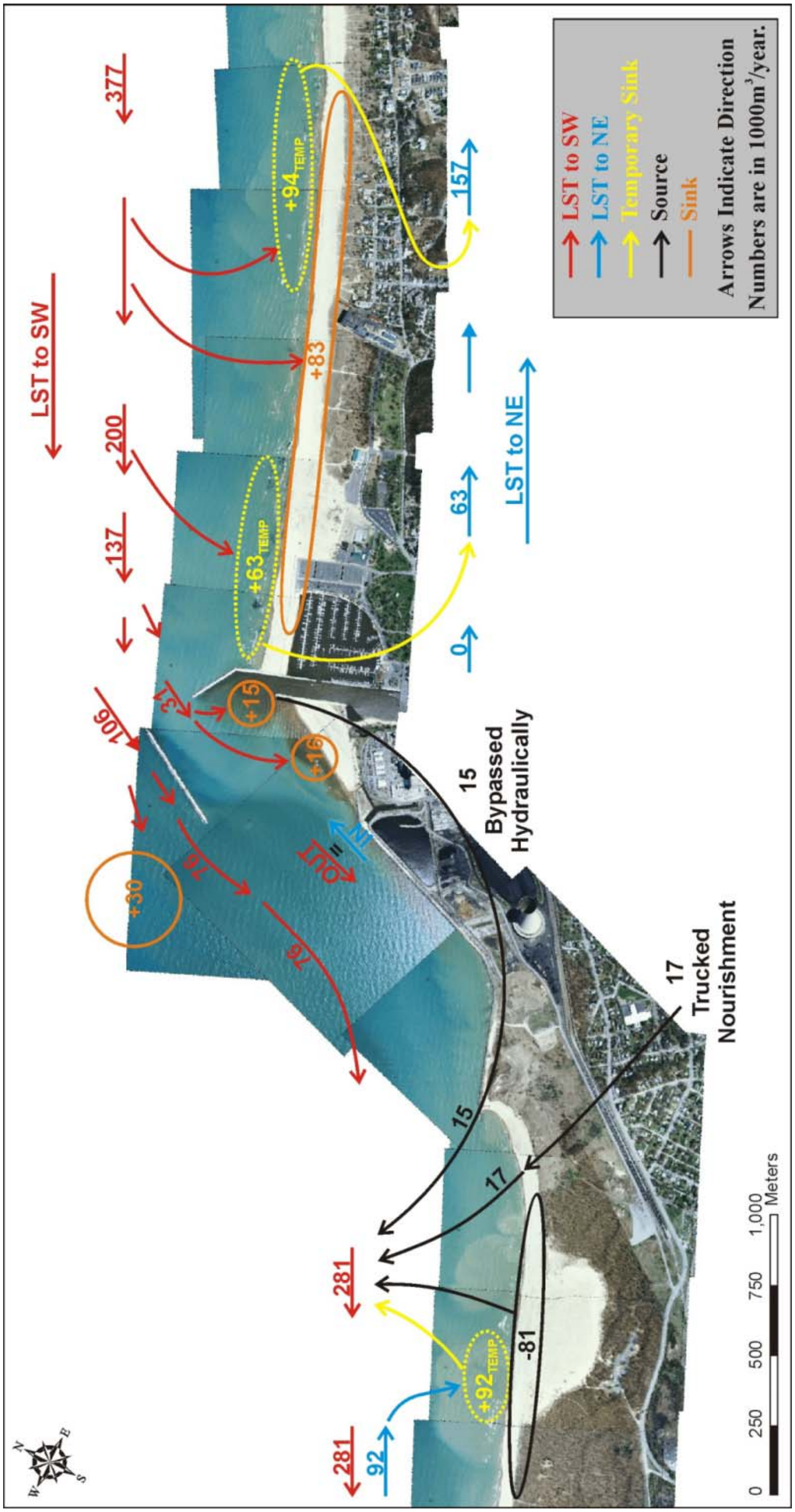


Figure 4.3-1 Michigan City Sediment Budget for Existing Conditions

5.0 EVALUATION OF DMMP ALTERNATIVES

The following sections summarize several proposed components for a new Dredged Material Management Plans for the Michigan City Harbor and adjacent shorelines. They are discussed individual with particular attention to the criteria listed in the Scope of Work, such as: 1) changes in dredging for the navigation channel, 2) change in dredging for the Michigan City Marina, 3) beach nourishment derived from dredging, 4) contribution of beach nourishment to Mount Baldy, 5) changes to usable beach area for recreation, and 6) costs over a 20 year planning horizon.

The following unit costs were provided by the USACE for various types of dredging operations and beach nourishment: 1) suction type dredge - \$8.50 cubic meter, 2) clam shell dredge - \$10.50 cubic meter, and 3) beach nourishment trucked from upland sources - \$7.00 tone. A fixed unit cost of \$10/cubic meter will be used for the dredging cost estimates and \$11/cubic meter for beach nourished trucked to Mount Baldy from upland sources.

The shoreline change analysis and sediment modeling described in the previous sections of the report indicate that the rate of deposition in the fillet beaches and bypassing shoal for the Michigan City Harbor has reduced in the last 50 years. Sand is now bypassing the harbor along a sediment pathway offshore of the harbor structures (i.e. the offshore breakwater). No significant sediment bypassing occurs between the East pier and offshore breakwater.

It is worth noting that the sediment budget identified a downdrift deficit of 81,000 cubic meters per year which is realized through shore erosion (lake bed and dunes). Interestingly, this deficit is similar to the anticipated future deposition rate in the updrift fillet (refer to Figure 4.3-1). Therefore, even for the status quo in Alternative 1, Mount Baldy will continue to erode in the future.

5.1 Alternative 1 – Continue Current Dredging Program

Since 1920, approximately 20,000 m^3 of sediment has been dredged from the Michigan City on an annual basis. Of this total, roughly 25% was from the inner harbor and likely associated with river sedimentation. Therefore, it is assumed that a volume of 15,000 m^3/yr will be dredged from the harbor in the future to maintain safe depths in the navigation channel. Using a dredging unit cost of \$10/cubic meter and ignoring the impact of inflation, the annual maintenance dredging will cost \$150,000 in the future.

Between 1974 and 2001, 476,000 cubic meters of sediment have been trucked to Mount Baldy from upland sources and placed on the beach. Using the unit cost above for trucked sand, the cost of the nourishment was \$5.2M. Annualized, this represents a cost of \$187,000 and will be considered representative of future expenditures.

Combined, the current dredging and beach nourishment activities at Michigan City cost approximately $340,000 annually. Over the twenty year period of the analysis, the total cost for maintaining the status quo is $6.7M. Refer to Table 5.1-1 for additional details. It should also be mentioned that Alternative 1 doesn't address the 81,000 cubic meter downdrift deficit in the sediment budget. If the deficit is addressed with additional trucked nourishment, the costs for Alternative 1 increases to $24.6M. See Table 5.1-1.

5.2 Alternative 2 – Conduct Limited Excavation of West Accretion Fillet

The west accretion fillet is dredged to a depth of 4 m below LWD for Alternative 2. Using the 2004 LIDAR data, this represents a volume of 200,000 cubic meters, which would be hydraulically pumped to Mount Baldy. Table 5.1-1 summarizes the projected impacts and costs of this alternative.

Since the storage of the west fillet increases by 200,000 cubic meters, there is expected to be a minor decrease in the dredging requirements for the navigation channel. This benefit will be realized during storms from the West. Storms from the North will still result in channel sedimentation between the East Pier and offshore breakwater.

The estimated cost to dredge the West accretion fillet is $2M. Dredging costs for the navigation channel will decrease to $2M. There will be no change to the Michigan City Marina dredging requirements. The nourishment pumped hydraulically to Mount Baldy will delay the trucking requirement for twelve years and reduce the beach nourishment costs by approximately $2.2M. The total cost for Alternative 2 is $5.5M. As in Alternative 1, the present 81,000 cubic meter downdrift deficit is not addressed with this option and erosion will continue at Mount Baldy. If additional sediment is trucked to the downdrift beaches (81k/yr), the cost for Alternative 2 increases to $23.3M.

There will be no changes to the area of usable beach at Washington Park and a minor increase in beach area at Mount Baldy for approximately 12 years. In summary, the beaches in the National Lakeshore receive a large infusion of sediment following the dredging of the West fillet that will last 10 to 12 years. The benefits are essentially equal to Alternative 1, however the cost is reduced slightly because relocating sediment by hydraulic dredging is less expensive than trucking sediment from upland.

5.3 Alternative 3 - Excavate Government Beach and Pump to Mt. Baldy

For Alternative 3 the shoreline along Government Beach is returned to its 1970's position, which was adjacent to the East breakwater. A total of 2M cubic meters of sediment is removed with a suction dredge and pumped hydraulically to Mount Baldy. Conversely, the shoreline at Mount Baldy is returned to the 1970's position. The 2M cubic meters of sediment placed hydraulically will be sufficient to maintain the existing shoreline position at Mount Baldy for 20 years, so no trucked nourishment is required. The cost to dredge Government Beach is $20M.

It is estimated that Alternative 3 will reduce the maintenance dredging in the navigation channel by 33% to $2M over the 20 year period. The reduction is small considering the large scale of the updrift dredging because sediment will still enter the navigation channel during West storms. The Michigan City Marina, on the other hand, may see some reduction in aeolian transport over the East breakwater, which ultimately leads to sedimentation

The usable beach area at Government Beach would be reduced following the completion of dredging for Alternative 3. However, given the vast beach width at the park, there would still be a sizable dry beach for recreation. Conversely, the beaches fronting the National Lakeshore would increase in size dramatically, returning to their position of the 1970's. However, this wider dry beach may lead to greater onshore losses to the center of the parabola at Mount Baldy. In addition, immediately following the nourishment, the beach would be an order of magnitude wider than needed to protect the shoreline from storm damages.

The cost for Alternative 3 over the 20 year planning horizon is $22M, which is approximately three times greater than the current dredging and placement costs (Alternative 1). However, when compared to the costs for Alternative 1 with zero downdrift erosion ($24.6M), Alternative 3 is actually less costly than Alternative 1.

5.4 Alternative 4 –Dredge Behind Detached Breakwater

Alternative 4 considers dredging the area defined by the West pier, NIPSCO plant and the offshore breakwater. The estimate volume to return this area to a depth of 4 m below LWD is 0.5M cubic meters. Based on the current volume of sediment trucked to the beaches at Mount Baldy, Alternative 4 would negate this requirement for over 20 years. Therefore, downdrift beach nourishment from trucking is not required for the cost estimate. A cost of $1M is projected for maintenance dredging in navigation channel. Therefore, the total cost of Alternative 4 is $6.0M, which is a 11% cost reduction versus Alternative 1. As with Alternative 2, hydraulically bypassing sediment is cheaper than trucking costs. If Alternative 4 is modified to have no downdrift erosion, the total cost increases to $22.1M.

There would be no changes to the dredging requirements for the Michigan City Marina for Alternative 4 or the usable area of Government Beach. The usable beach area at Mount Baldy would increase for the 20 year period.

5.5 Alternative 5 – Combine Alternatives 3 & 4

Alternative 5 includes both dredging of Government Beach and the West accretion fillet, for a combined volume of 2.0M cubic meters. The cost to dredge this volume of material and pump hydraulically to Mount Baldy is $20M. With this large volume of beach nourishment for the National Lakeshore, no trucking will be required for Alternative 5. However, some maintenance dredging will still be required for the navigation channel and it is estimated at $1M over the 20 year planning horizon. The total cost for Alternative 5 is $21M, which is three times greater than the current dredging and nourishment operation (Alternative 1). However, when compared to the cost for Alternative 1 with no downdrift erosion, it is actually less expensive (see Table 5.1-1).

Some reduction in aeolian transport into the Michigan City Marina would be anticipated for Alternative 5, as the beach fronting the East breakwater is removed. However, there would also be a significant reduction in the usable area of the dry beach for the East fillet. Mount Baldy and the National Lakeshore would see a significant increase in the width of the dry beach over the 20 year planning horizon. However, as in Alternative 3, the nourishment would immediately start to erode to supply the downdrift deficit.

5.6 Alternative 6 – Bypassing Plant for East Fillet and Pipe to Mount Baldy

Alternative 6 considers the costs and benefits of installing and operating a bypassing plant for the East fillet beach. The sediment trap for the plant would be located somewhere in the vicinity of the Michigan City Marina and the tip of the East pier. A spur jetty off the East pier might be required to develop an efficient trap. The plant would pump sediment and water under the navigation channel to the downdrift shoreline West of the NIPSCO plant. Initial construction costs and maintenance over the 20 year planning horizon are estimated at $20M for the plant. Once the plant is operational, there will be maintenance costs but no downdrift nourishment requirements for the National Lakeshore. Some maintenance dredging for the navigation channel is still anticipated and estimated at $2M over the 20 year planning horizon.

The total cost for Alternative 6 is $22M. This cost is significantly more than the status quo for Alternative 1 (See Table 5.1-1), but actually less than the costs for Alternative 1 with zero downdrift erosion ($24.6M).

5.7 Alternative 7 – Extend West Pier

Alternative 7 deals specifically with the sedimentation issue in the navigation channel and proposes to extend the West pier to an equal length of the adjacent East pier. The estimated length of the pier extension is 250 m, which translates to a cost estimate of $2.5M. The extended pier is expected to reduce future maintenance dredging by 66% to $1M over the twenty year planning horizon. There will be no changes to the usable beach area updrift or downdrift of the harbor and dredging requirements for the Michigan City Marina will not change. The current beach nourishment program would continue for the beaches fronting Mount Baldy at a cost of $3.7M over the planning horizon. The total cost for Alternative 7 is $7.2 M, which is close to the current estimated expenditures for the status quo over the next 20 years. The cost increases to $25.1M if the goal is zero downdrift erosion.

To determine if a West pier is a viable component of a future DMMP, addition economic calculations were needed. When absolute dollars are considered, the one time economic investment for the pier extension is $2.5M. This structural solution is contrasted with annual maintenance dredging over the 20 year planning horizon at $150k/year. Over the 20 year period, channel dredging costs $3M. However, to complete an equitable economic comparison, it is necessary to calculate the Present Value (PV) of each future annual dredging expense and then sum the results. Figure 5.7-1 presents the results of the PV calculation for a $150k dredging expenditure 1 to 30 years in the future using an interest rate of 4%.

For example, the PV of dredging the navigation channel in 5 years is $123k, while the cost decreases to $56k in year 25. The sum of the PV calculations using a 4% interest rate over the 20 year study planning horizon is $2M. In other words, maintenance dredging is more economically viable the installing a structural solution over the 20 year planning horizon, especially considering there still may be some maintenance dredging even with the West pier extension.

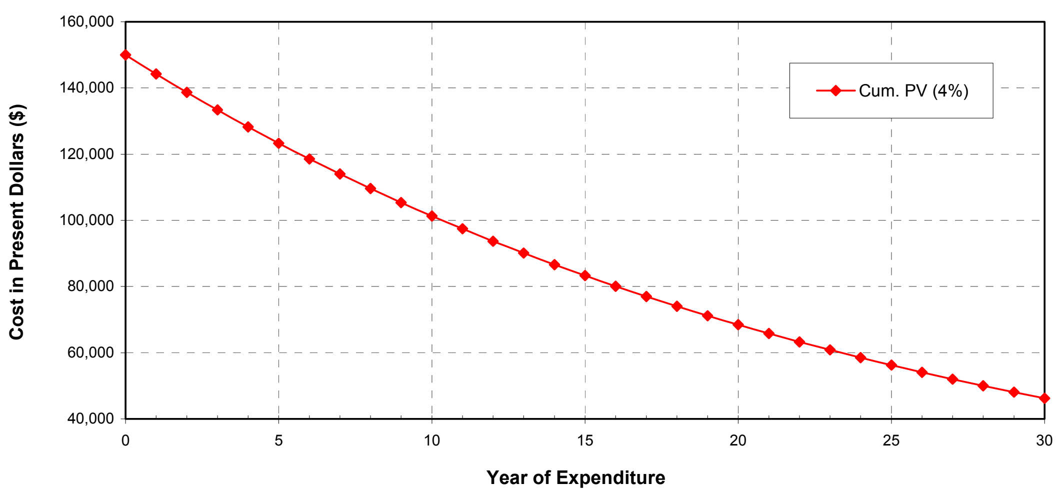


Figure 5.7-1 Present Value Calculations for Dredging Expenditures 0 to 30 years in the Future

However, it is worth considering that the capital investment for the West Pier extension will have economic benefits for more than 20 years. In other words, the Pier will still be reducing maintenance dredging well beyond the 20 year planning horizon selected for the analysis of DMMP alternatives. In Figure 5.7-2 the cumulative PV calculations are plotted using three interest rates and a planning horizon of 40 years. The PV of dredging for the next 40 years ($1M) is added to the capital costs for the pier ($2.5M) and also plotted on Figure 5.7-2. There may be some convergence of the pier costs and maintenance dredging after 40 years, depending on the interest rate selected. However, after 40 years, maintenance of the pier would also need to be considered to complete the analysis. Further analysis of Figure 5.7-2 requires additional information in interest rates, structure costs and maintenance, and anticipated future dredging with the pier.

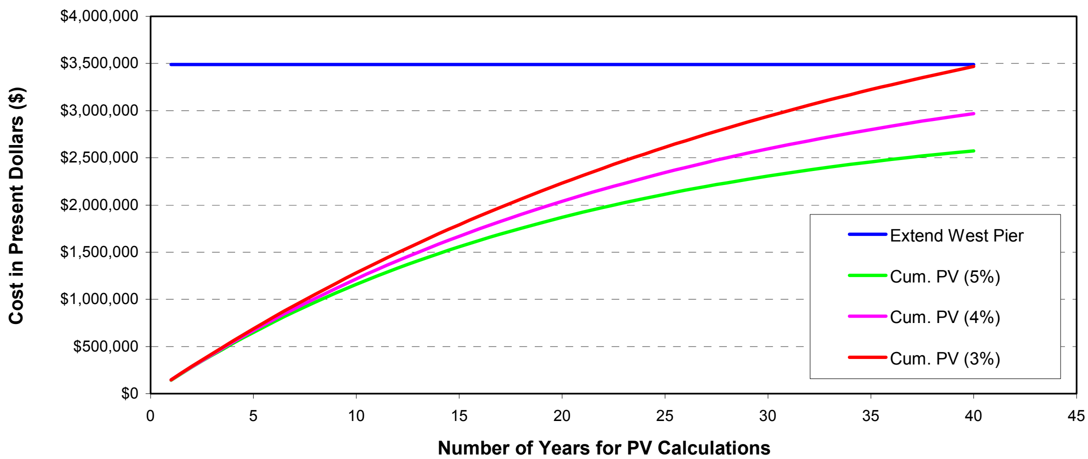


Figure 5.7-2 Cumulative PV Calculations for 0 to 40 years versus Pier Extension

5.8 Alternative 8 - Structural Solutions at Mount Baldy to Retain Beach Nourishment

Since the early 1970's, almost 700,000 m^3 of beach nourishment has been placed on the beaches fronting the Mount Baldy and the other dunes of the National Lakeshore. Since there is a sediment deficit downdrift of the harbor, this placed sand is quickly mobilized by longshore currents and transported to the west. There is certainly benefits to the shorelines west of Mount Baldy, such as Beverly Shores, once the nourishment is eroded. However, Alternative 8 considers whether the benefit to cost ratio for the placed sand could be enhanced with the construction of a limited number of small shore parallel structures, such as offshore breakwaters (emerged or submerged). Conceptually, the structures would be located between the western terminus of the NIPSCO seawall and the eastern terminus of the Beverly Shores revetment. The goal would be to widen and stabilize the existing beach fronting the relic dunes downdrift of the harbor and provide erosion protection during storms from the West.

The costs associated with Alternative 8 are summarized in Table 5.1-1. It is estimated that approximately 400 m of structures would be required at a cost of $2.8M. The current maintenance dredging program for the navigation channel would still be required at a cost of $3M over the 20 year planning horizon. Beach nourishment requirements are estimated to reduce by 50% over the planning horizon to $1.87M. Collectively, the total cost for Alternative 8 is $7.5M, which is comparable to the costs associated with the current dredging and nourishment programs. Since downdrift structures are not required if the trucked volume equals the downdrift deficit, a cost was not computed for the last column in Table 5.1-1.

The alternative doesn't change the usable beach area for Government Beach and expands the usable area for the National Lakeshore. No changes are anticipated for the dredging requirements for the Michigan City Marina.

It is worth noting that the duration of the planning horizon (i.e. 20 years) doesn't favor the comparison of structural solutions, such as offshore breakwaters, to the present beach nourishment practices, as was demonstrated with the PV analysis for Alternative 7. Therefore, considering the structures would have a design life of greater than 20 years, the economic benefits associated with reduced beach nourishment placement volumes would also continue into the future.

5.9 Alternative 9 - Stabilize Dunes in the National Lakeshore with Native Vegetation and Controlled Access

Mount Baldy is an eroding parabolic dune. As outlined in Section 1.5.5, onshore breezes erode and entrain sand from the beach and the gentle windward slope. As wind speeds accelerate up the unvegetated slope, aeolian transport moves sand up and over the parabola, leading to the migration of this large dune into the forest. Given that there is very little embryo or foredune development fronting Mount Baldy, some percentage of the sediment migrating over the parabola is coming from the beach and represents a permanent sink from the sediment budget. Considering there is already a downdrift deficit west of the harbor, this sink has a negative impact on the local recession rates for these relic dunes.

Examples of the beach and dune conditions for the National Lakeshore were presented in Photographs 25 through 29 of Figure 1.5.4-1. In some locations, a small embryo dune has formed during the recent low water level conditions on Lake Michigan. In others, no embryo dune or foredune is present, and the beach crest is very low. During average to high lake levels, storm waves will reach the back of the beach and erode the relic dunes. Alternative 9 considers the economic benefits of stabilizing these eroding dunes naturally with native vegetation and changes to the land use management practices for the National Lakeshore. For example, direct access to the dune slopes would be eliminated and controlled access to the beach would be provided for the park visitor. Controlling access across the dunes at other parks on Lake Michigan has been successful in minimizing human influences on fragile dune vegetation, which is key to natural stabilization. For example, field data collected at Hoffmaster State Park in Michigan during the current low lake level conditions suggest native dune grasses can trap upwards of 4 $m^3/m/yr$ of aeolian transported sand (van Dijk, 2003). A sample of the large foredune fronting the older relic dunes of the park is presented in Figure 5.9-1 and 5.9-2 below.

It is difficult to quantify the potential costs to provide controlled access to the beaches at

Figure 5.9-1 Foredune and Relic Dune at Hoffmaster State Park, looking north

Figure 5.9-2 Large Foredune fronting Relic Dune, March 22, 2003

the National Lakeshore and stabilize the foredunes naturally with dune grasses native to the Great Lakes, such as American or Champlain Beachgrass. An estimate of $2M is included for Alternative 9. Maintenance dredging would continue, at a cost of $3M over the 20 year period.

At Mount Baldy and the adjacent relic dunes, it will take time for the natural plantings to have a beneficial impact and park visitors to change the use patterns for the park. Also, the actual quantity of beach sediment that is blown over the parabola and contributing to the landward migration is not known. For the purpose of this economic analysis, a 25% reduction in the beach nourishment volumes are projected for the 20 year planning horizon. Therefore, beach nourishment will still cost $2.8M. The total cost for Alternative 9 is $7.8M, which is slightly higher than the current status quo program.

Considering that the dune will eventually migrate across a parking lot and road, this is a viable alternative to consider for a future DMMP.

5.10 Alternative 10 – West Pier Extension, Downdrift Structures and Natural Vegetation

Alternative 10 is a hybrid that combines Alternative 7, 8 and 9 to include a West Pier extension, downdrift structures and natural stabilization with vegetation and controlled access to the Natural Lakeshore. The cost of the West Pier extension is $2.5M. The cost of the downdrift structures is $2.8M, while $2M has been budgeted for the creation of trails around Mount Baldy and natural stabilization with native dune vegetation. Some downdrift nourishment will still be required and is estimated as $1.9M over the twenty year planning horizon. The total cost of Alternative 10 is $10.2M.

Table 5.1-1
Evaluation of DMMP Alternatives

#	Description	Assumptions	Proposed Activity for DMMP	Cost of Proposed Activity	# of Years Channel Dredging Required	Details of Channel Dredging for Remaining Years	Cost for Dredging Nav. Channel over 20 Years	# of Years Beach Nourishment Required	Details of Beach Nourishment for Remaining Years	Cost of Beach Nourishment for Remaining Years	Total Cost for Alternative	Total Cost with No Downdrift Erosion
1	Continue Current Dredging Program	n/a	none	$0	20	Existing Dredging 15k@$10/m3*20y=3M	$3,000,000	20	Existing Nourishment is 17k/yr $187k/y*20y=3.74M	$3,740,000	$6,740,000	$24,560,000
2	Conduct Limited Excavation of West Accretion Fillet	Sediment hydraulically pumped to Mount Baldy. Volume is 200k cubic meters	Dredge West Fillet to -4m LWD 200k@$10/m3=2M	$2,000,000	20	Dredging required at reduced level 10k@$10/m3*20y=2M	$2,000,000	8	Nourishment replaces trucked sediment for 12 years (200k/17k/yr=12yrs)	$1,496,000	$5,496,000	$23,316,000
3	Excavate Government Beach and Pump to Mount Baldy	Fillet returned to 1970s conditions, parallel to East breakwater, vol. is 2M cubic meters	Dredge East Fillet Beach 2M@$10/m3=40M	$20,000,000	20	Dredging required at reduced level 10k@$10/m3*20y=2M	$2,000,000	0	Not required	$0	$22,000,000	$22,000,000
4	Dredge Behind Detached Breakwater and West Fillet	Dredge area bwn off. b/w, west pier and NIPSCO (to -4m). Vol. is 0.5M cubic meters	Dredge West Fillet Region 0.5M@$10/m3=5M	$5,000,000	20	Dredging required at reduced level 5k@$10/m3*20y=1M	$1,000,000	0	Nourishment replaces trucked sediment for 29years (500k/17k/yr=29yrs)	$0	$6,000,000	$22,137,000
5	Combine 3 and 4	Dredge 2.0 million cubic meters from Gov. Beach and West Fillet Beach	Dredge Harbor Area 2.0M@$10/m3=2M	$20,000,000	20	Dredging required at reduced level 5k@$10/m3*20y=1M	$1,000,000	0	Not required	$0	$21,000,000	$21,000,000
6	Bypassing Plant for East Fillet and Pipe to Mount Baldy	Plant mechanically bypasses sediment collected in East fillet beach trap	Install Bypassing Plant at a cost of 20M	$20,000,000	20	Dredging required at reduced level 10k@$10/m3*20y=2M	$2,000,000	0	Not required	$0	$22,000,000	$22,000,000
7	Extend West Pier	Extend West Pier (only addresses maintenance dredging)	Construction costs of 250m*$10k/m=2.5M	$2,500,000	20	Dredging required at reduced level 5k@$10/m3*20y=1M	$1,000,000	20	Existing Nourishment is 17k/yr $187k/y*20y=3.74M	$3,740,000	$7,240,000	$25,060,000
8	Structural Solutions at Mount Baldy to Retain Beach Nourishment	Structures prolong life of beach nourishment (e.g. offshore b/w)	Construct a series of offshore b/w's 400m*$7k/m=2.8M	$2,800,000	20	Existing Dredging 15k@$10/m3*20y=3M	$3,000,000	10	Existing placement requirements decrease by 50%	$1,870,000	$7,670,000	
9	Stabilize Dunes in National Lakeshore with Native Vegetation	Interior of Mt Baldy and all foredunes stabilized naturally with vegetation	Difficult to quantify. Includes trails and vegetation planting. Assume 2M	$2,000,000	20	Existing Dredging 15k@$10/m3*20y=3M	$3,000,000	15	Stabilization reduces aeolian losses at Mount Baldy and builds protective embyro dunes	$2,805,000	$7,805,000	
10	Combine Alternatives 7, 8 and 9 (West Pier, Downdrift Structures and Planting)	Extend West Pier, some Downdrift Structures and Natural Planting	Pier=2.5M Structures=2.8M Stabilization=2M	$7,300,000	20	Dredging required at reduced level 5k@$10/m3*20y=1M	$1,000,000	10	Existing placement requirements decrease by 50%	$1,870,000	$10,170,000	

Unit Costs and Volumes:
1. Status quo for future channel dredging is 15,000 cubic yards per year
2. Unit cost for dredging and relocation to beaches fronting Mount Baldy is $10/cubic yard
3. Downdrift beach nourishment requirements for Mount Baldy and adjacent shoreline is 17,000m3/yr*$11/m3=$187,000/yr
4. Annual loss rate at Mount Baldy is 81,000 cubic meters/year for Alternative 1 (status quo)
5. Unit costs for structures and bypassing plant are conceptual

6.0 CONCLUSIONS AND RECOMMENDATIONS

Section 6.0 of the report provides study conclusions and recommendations for a future DMMP.

6.1 Conclusions

The following important conclusions can be drawn from the coastal investigation, including:

- Deposition in the updrift fillet beach and offshore bypassing shoal has reduced in the last 50 years. However, full bypassing has not developed at the harbor and there is presently annual downdrift deficit of 81,000 cubic meters,

- Sedimentation in the navigation channel will continue indefinitely due to the local wave climate and hydrodynamics at the harbor. A West pier extension may reduced dredging requirements in the future. However, addition study is required to provide final recommendations,

- Aeolian transport over the East breakwater and into the Michigan City Marina is a natural process and expected for a wide fillet beach. Sedimentation is related to poor planning when citing the marina location. It is uncertain whether the new wall under construction will reduce aeolian transport. Most of the DMMP alternatives discussed in Section 5.0 will not reduce the future sedimentation problem,

- There is a significant area of usable beach updrift and downdrift of the Michigan City Harbor. It is not expected that the DMMP discussed in Section 5.0 will have a negative impact on usable beach area,

- This downdrift deficit at the harbor contributes to the erosion problems at Mount Baldy and the other dunes in the National Lakeshore. Erosion is expected to continue indefinitely with the present dredging and beach nourishment programs,

- Significant benefit could be realized by eliminating foot access across the Mount Baldy dune and stabilizing the foredune and slope with native dune grasses. Future migration of this dune is not sustainable and definitely not helping with the beach erosion problems.

6.2 Recommendations for DMMP

Several Alternatives for a future DMMP were reviewed and analyzed in Section 5.0. Costs were compared to the current status quo, which is Alternative 1 and a modified Alternative 1 that would eliminate all downdrift erosion associated with the harbor. The estimates ranged from $5.5M to $25M.

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